SNOW COVER CHANGE DETECTION WITH LASER SCANNING RANGE AND BRIGHTNESS MEASUREMENTS

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ABSTRACT

We investigated the use of terrestrial laser scanner (TLS) range and brightness data for the measurement of seasonal snow cover. A practical application of a newly developed calibration technique for laser scanner intensity, based on calibrated reference targets for airborne and terrestrial use, is demonstrated. We applied this technique in snow cover measurements, and demonstrate that changes in the snow cover (snow pack height, changes in grain size/shape and overall wetness) are observable in terrestrial laser scanner range and brightness data, and call for development of new TLS-based snow monitoring methods. The role of other factors in the laser intensity measurement and calibration for snow, such as the incidence angle of the laser beam to the surface, is also discussed.

INTRODUCTION

Range measurements with terrestrial laser scanning (TLS) have recently found applications in remote sensing and earth studies (1). The application of laser scanners in mobile platforms (e.g. ground based vehicles) is also becoming available and shows more potential in environmental applications (e.g., 2). Similarly to airborne laser scanners (ALS), terrestrial scanners also record the intensity value of a given point. The use of these values has been limited due to the lack of calibration processes, and because the intensity detectors are mostly optimised for range rather than reflectance measurement.

The most common detectors used in TLS measure the radiance, i.e. the flux of photons entering the receiver from a given direction and solid angle. The radiance is related to the power of the received signal, and hence to the reflectance of the target. The (directional) hemispherical reflectance (albedo) is the total fraction of the incident collimated power on the unit surface area, which is scattered into the upper hemisphere by the unit area of surface (3). Laser scanners measure only the part of reflectance that occurs in the direction of illumination (0° angle between light source and detector), i.e. the backscattered reflectance. The recent calibration approaches are based on either investigating the power incident on the target (i.e., the laser power of the scanner), or using standards of known reflectances measured in the same conditions (4,5,6). Detailed reviews of the physical concepts of laser scanner intensity calibrations are found in (6,7).

We have developed a reflectance calibration scheme for both terrestrial and airborne laser scanning intensity data, based on the use of natural and commercial targets as reference. To establish a reference-based calibration method, repeated experiments were needed in both ALS and TLS as well as controlled laboratory measurements to find practical and stable targets that produce reliable results, see (5,8) for more details; the validation of these methods is a subject of our ongoing research related to airborne and terrestrial laser scanning. Results from campaigns (laboratory and *in situ*) with different calibration strategies (and benchmark activities) are expected in the near future.

Laser scanning is also becoming an increasingly important method for monitoring glaciers and ice sheets (e.g., (9)). The first applications of intensity data in glaciology have recently become available, and are mostly related to target discrimination in glaciers (9,10).

The snow-forest interaction in the boreal regions is closely related to the rapid environmental and climate changes. As the snow-vegetation albedo is an important parameter in climate models (11), a long-term change detection of snow brightness is needed in the investigation of climate trends, especially in boreal regions, where strong effects of the global change are expected. However, this kind of data is mostly not available in boreal regions, because of practical limitations related for example to costs and the boreal climate which reduces the satellite information coverage of the surface albedo due to the high frequency of cloud coverage (12). The recently ongoing validation campaigns of satellite and airborne snow monitoring have provided a possibility to test the performance and feasibility of ground based methods, particularly terrestrial laser scanners in either stable or mobile platforms. Ground based applications are cost-effective and provide a possibility of long term monitoring of test sites and environmental targets, for example. Terrestrial techniques are also suitable when more detailed monitoring is needed than, e.g., with satellite-based mapping; see (12) for a summary of snow monitoring satellite optical and radar imagery. TLS has found applications in monitoring the snow distribution in potential avalanche zones in the Alpine regions (13,14), for example.

In this paper we test the reference target based TLS intensity calibration approach (8) in the monitoring of snow surfaces, and investigate the role of snow parameters in both range and intensity data. We present the first results of the test campaign, and briefly discuss some other factors that must be taken into account in laser scanner intensity calibration.

METHODS

The instrument used in this study was a 785 nm FARO LS880HE80 terrestrial laser scanner. The scanner uses a phase modulation technique for the distance measurement with the accuracy of 3-5 mm and 360°×320° field of view. The detector of the scanner is not optimised for intensity measurements: there is, e.g., a logarithmic amplifier for small reflectances and a brightness reducer for near distances. Additional corrections to the intensity data have therefore been carried out for the effects of the amplifier and reducer to get a linear brightness scale, based on instrument calibration experiments for both distance and reflectance scales using reference targets (see (8) for more details). The 785 nm wavelength is ideal for snow reflectance, because the absorption from snow is stronger at wavelengths greater than1000 nm, which would reduce the signal recorded by the intensity detector (15). The average error in intensity in our previous experiments has been in the range of 1-2% for FARO (5).

The test site is located in Masala, south coast of Finland, where the air temperatures are subject to variation around 0°C throughout the winter. Due to the temperature limit in the operation of the scanner (0°C), the test area was scanned with the scanner placed on the open window (Figure 1). Together with the large field of view of the scanner, this also allowed the reflectance standard (Spectralon® (Labsphere Inc.) calibrated multi-step target of 12%, 25%, 50%, and 99% reflectance) to be placed inside. The individual scannings (i.e. the data between different dates) were georeferenced to a common coordinate system using five stable reference targets in the scanned area. These targets are fixed and allow a long-term time series of the test area (which these snow measurements were a part of). The manufacturer reported systematic distance error for the FARO scanner is ±3 mm at the distance of 25 m.

Three test plots were selected from the scanned area, with distances of about 8.7 m (Low), 22.8 m (Middle), and 27.8 m (High) from the scanner, respectively. The reference panel was placed at a distance of about 4.2 m from the scanner. Table 1 provides the air temperatures (at the time of the measurement) and the snow cover depth and average grain size information.

For the intensity of each test plot, a square-shaped small area was extracted from the intensity images. The intensity value was taken as an average of a square, and the detector corrections (e.g. the effect of distance and the logarithmic amplifier of the detector) as well as a calibration with Standard (sampled similarly to the snow targets) were applied (see more details in (8)). The 99% panel in the Spectralon target was saturated, i.e., the counts were too high for a reliable intensity calibration, and we therefore used the 50% panel as a reference in this experiment.

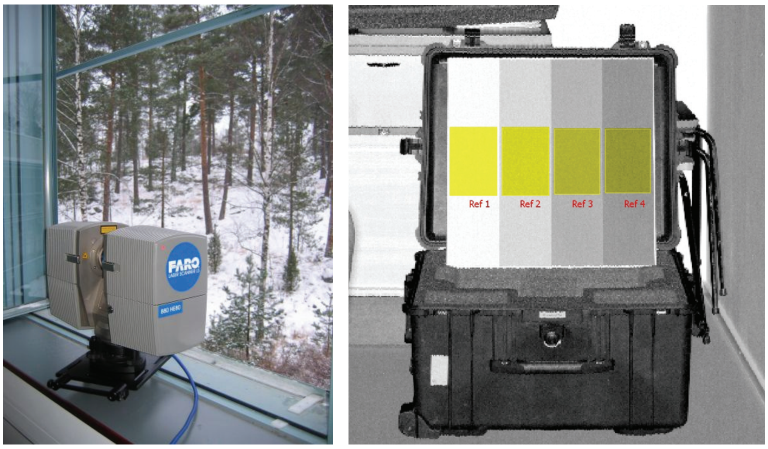

Figure 1: Left: the FARO scanner placed for the measurement, facing the test site. Right: intensity image of the 4-step reference target, showing the sampling of the intensity for each panel.

Table 1: Air temperatures and snow cover depth and average grain size characteristics on each measurement date. The average grain (aggregate) sizes were approximated visually using a scaled magnifier loupe (and camera images taken through the loupe).

Date	Air temperature (°C)	Snow cover depth (cm)	Average grain size (mm)
Feb 1 2007	-5.0	23	0.75
Feb 2 2007	+2.5	20	0.25
Feb 9 2007	-12.0	23	0.1
Feb 26 2007	-6.5	19	1.0
Mar 2 2007	+2.2	22	1.5
Mar 6 2007	+2.5	18	1.7
Mar 9 2007	+3.5	16	2.0
Mar 20 2007	+7.0	10	1.5
Jan 9 2008	-1.0	8	0.2
Jan 10 2008	+2.5	5	1.0

RESULTS

Snow monitoring from range and intensity data

Changes in the height of the snow pack can be observed in the FARO scanner range data (Figure 2). The height of the snow pack was also measured *in situ* with a stick measure with an accuracy of about 1-2 cm. This measurement is suggestive, because it was taken at a point near the Low test plot (to keep the test plot itself untouched for scanning). Nevertheless, the agreement of the stick measurement with the height derived from the *z*-coordinate from the FARO measurements is within a few centimetres (see Figure 2, lower graphic) and both curves follow the same trends. The agreement is better in 2008 measurements, which may indicate better homogeneity in the snow cover in the area than in 2007.

The un-calibrated FARO intensity images (raw data) from 4 separate dates are shown in Figure 3. Changes in the snow cover can be observed, and also the fading over distance is clearly visible. The intensity values (counts) for the Middle and High (no. 2 and 3) test plots were significantly lower than that from the Low (no. 1) plot. Previous experiments have shown that data points with too low counts are also inaccurate with respect to the range measurement (as well as the intensity). Therefore, we only included the Low test plot in the further study. That would also minimise the effect of incoming solar radiation, since the Low plot was shaded by the house, and the reflection effects from the surroundings were also small due to the distance of only 8.7 metres.

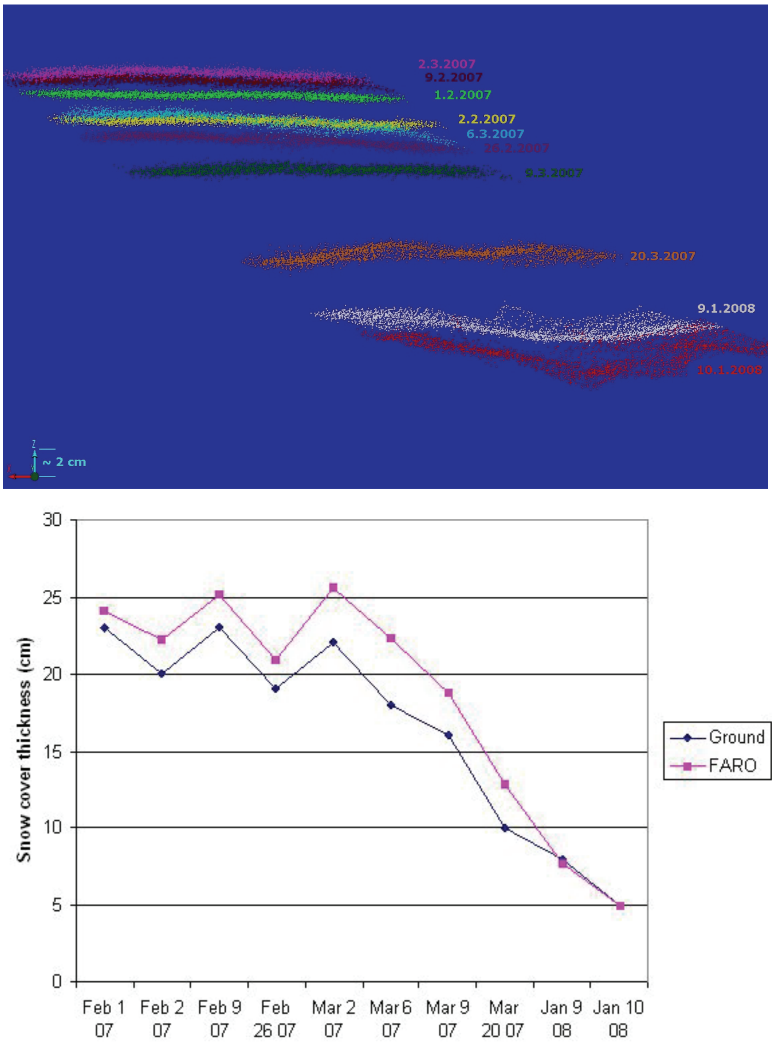

Figure 2: Above: point cloud profiles of snow surfaces at different dates plotted in the same x,y,z-scale. Below: comparison of snow depth derived from the FARO z-coordinate (Low plot, cf. Figure 3) with in situ (ground) measurements near the plot.

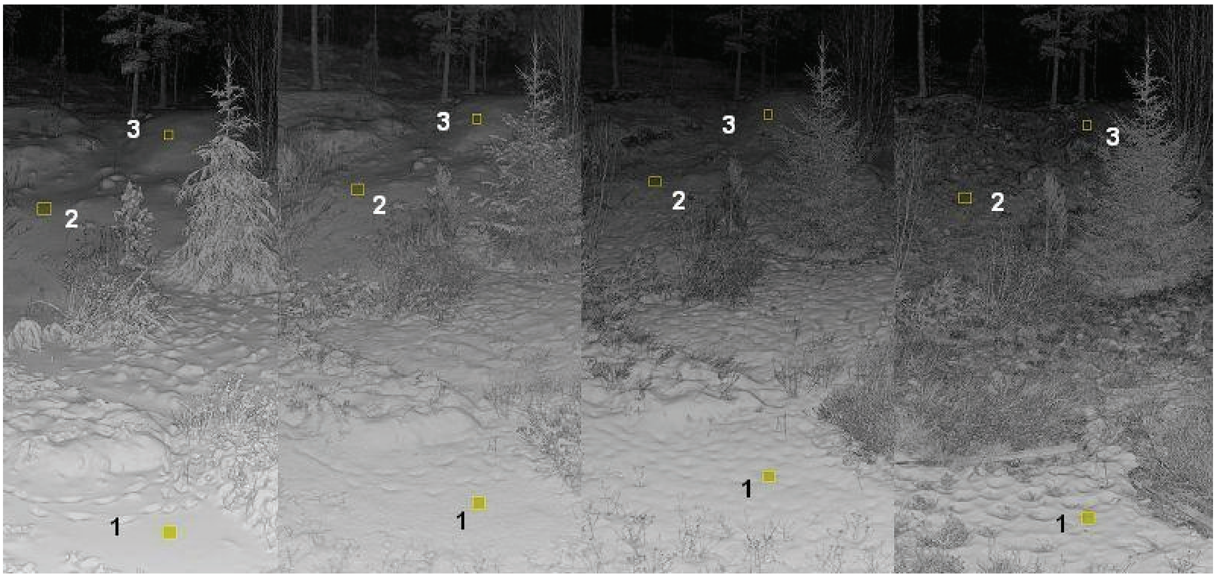

Figure 3: FARO intensity images (Feb 1, Feb 9, Mar 6, and Mar 20, 2007): changes in snow cover are visible in the intensity images, e.g. snowmelt towards the rightmost image (Mar 20). The data collection plots Low (no 1), Middle (no 2), and High (no 3) are marked with yellow squares.

The calibration of laser scanner intensity is based on reference targets, which are applied similarly to laboratory and field measurements in BRDF (bidirectional reflectance distribution function) spectroscopy and laser backscatter measurements, for example. We have extended this method into laser scanning intensity and use of natural and commercial targets as references. The first results from airborne and terrestrial laser scanning test campaigns indicate that intensity calibration is possible with natural or artificial reference targets (5,8).

The calibrated FARO intensities are plotted in Figure 4 for all three test plots (showing also the remarkable difference in the reflectance of the Low plot compared to the other two plots). We found no relation to a single parameter (snow cover thickness, temperature, grain size, etc.) in the intensity values which indicates that the intensity is affected by several parameters. Moreover, there are limitations to the accuracy of laser intensity measurement from snow, caused by strong multiple scattering inside the layer (16), for example; and while more extensive studies on laser reflection from snow are in progress, the laser intensity from snow should be studied in relative sense rather than the accurate reflectance values. Therefore, we compared the relative changes in intensity of the Low test plot in Figure 5.

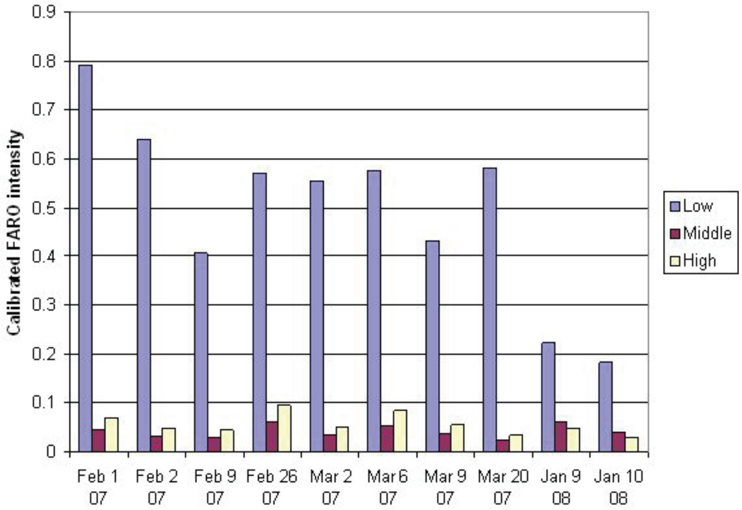

Figure 4: Intensity time series for all three test plots 2007-2008. The intensities (counts) from the Middle and High plots were significantly lower that those from the Low plot.

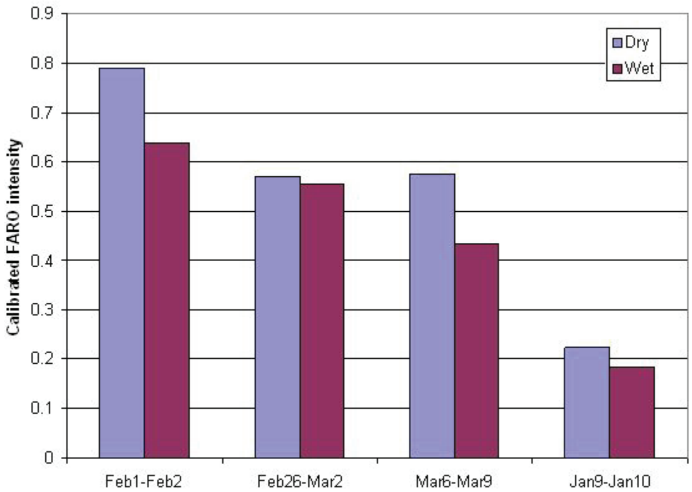

Figure 5: Calibrated FARO intensities of the lowest snow test plot. The temperature changes were from -5°C to +2.5°C (Feb 1- Feb 2, 2007), from –6.5°C to +2.2°C (Feb 26 - Mar 2, 2007), from +2.5°C to +3.5°C (Mar 6 - Mar 9, 2007, here the temperature in both days was above zero, but there was a significant change of weather conditions and the snow cover changed from a dry layer to a wet and melting surface), and from -1°C to +2.5°C (Jan 9 - Jan 10, 2008) In all cases there was a change in weather conditions from (visually) dry to wet (e.g. recent rain).

We compared the changes in intensities of the Low test plot between two consecutive (or close) dates (Figure 5), where a change of (visually) dry to wet conditions had occurred, as well as the changes in the grain structure (most typically rounding). The wetness in snow was mostly due to melting at temperatures >0°C (and/or the recent rainfall), but in one case (Mar 6), a (re)frozen surface structure was still present even though the temperature was +2.5°C. An example of a change in grain structure is presented in the enlarged images in Figure 6, where samples of snow grains have been photographed through a magnifier loupe with a millimetre scale. A decrease in laser intensity is observed in all cases which suggests an effect of wetness on the backscattered reflectance of snow. A tentative comparison with the earlier results obtained with a laser backscatter measurement of snow (16) shows that the intensity levels for wet and melting snow were mostly higher than those for frozen samples, even though the relative increase in brightness (i.e. the hot spot effect) was stronger for melted samples and surfaces with rounded grain shape (see 16 for more details). There are also deviations in the overall intensity levels (e.g. the Feb 9 data point is not easy to compare, partly because it is the only sample with fresh fallen hexagonal snow grains). It is an important future task to establish the possible relation of snow wetness with backscatter reflectance and its interaction with other snow surface parameters in a better way.

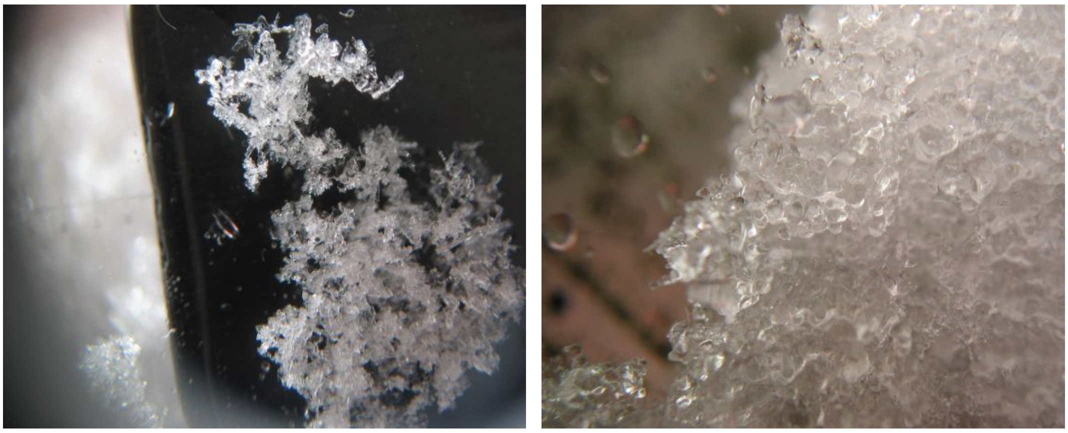

Figure 6: Snow grains in Jan 9 (left) and Jan 10 (right) photographed through a magnifier loupe. The average grain sizes in the image are approximately 0.1 - 0.5 mm and 1 mm, respectively.

Other factors affecting laser scanner intensity

We have also studied some other effects that must be taken into account in the more accurate study of snow cover brightness with lasers (and also other incoherent instruments). The effect of the incidence angle on snow intensity is clearly visible in intensity images (Figure 3). To evaluate this effect more accurately, we carried out a test measurement with the FARO scanner of a 5-cm snow layer on top of a plane (roof) surface. The incidence angle varied from 0° to about 70° in the measurements, and the calibration was carried out with the 99% Spectralon® standard placed at 1 m distance. We found a strong effect on the measured laser intensity (Figure 7), which is a significant factor, especially if snow layer intensities are compared between various locations with a different incidence to the surface. These results agree with those obtained with the same instrument for various remote sensing land targets (more details in (17)).

There are other important issues that must be further studied and taken into account in the calibration of laser intensity from snow, e.g. strong diffuse radiation inside the layer, which often causes the calibrated backscatter reflectances measured with laser to be significantly lower than one would expect from the reported snow albedo (hemispherical reflectance) values in the literature. Whether this is only caused by the behaviour of laser light in the snow layer or the weakness of the backscattered fraction of snow hemispherical reflectance, is a subject of further studies. Weather (temperature) affects the scanning intensity and the performance of the scanner detector, which may also complicate the calibration. A further discussion on the crucial factors and corrections to airborne and terrestrial laser scanning intensity is in (5).

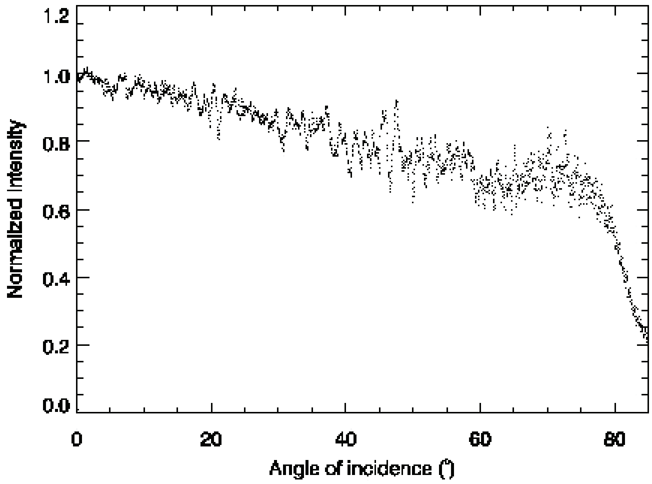

Figure 7: Intensity of a 5-cm snow layer as a function of the incidence angle. The effect of distance to the scanner has been normalised to 1 m. The intensity is normalised to 1 at 0° in this plot.

CONCLUSIONS

We have studied the use and performance of terrestrial laser scanning in snow cover measurement in order to develop methods for terrestrial laser scanner based snow cover change detection and long-term monitoring applications. It has been observed that snow cover wetness affects the backscattered laser intensity, even though there is deviation in the measured intensity levels. It has also been found out that even small changes in the snow cover depth are measurable with a TLS, if stationary reference targets are available. The practical performance of the TLS instrument plays an important role in the accuracy of the results, especially at longer distances. We are also studying the use of commercial and natural reflectance targets as reference standards, since larger target sizes (than those used in the laboratory), e.g. 5 m × 5 m, are needed in airborne and long-range terrestrial laser scanning.

Further studies are needed for both laboratory and scanner based laser intensity calibration for snow surfaces to confirm these results and their interpretation, as well as to evaluate and improve the accuracy and search for connections with physical parameters. The fact that melting and liquid water affects the reflectance of a snow surface is nevertheless observable with laser instruments; and this calls for the development of laser scanner based snow monitoring methods. This would be especially useful as there is an increasing interest in mobile (vehicle-based) mapping applications which employ terrestrial and airborne laser scanner instruments and produce an increasing amount of environmental 3D-data in the near future.

More studies on laser reflection from snow are called for in order to improve the calibration of laser intensity of snow surfaces (16) and to find out how well the backscatter reflectances correlate with those measured with incoherent reflectance instruments, such as spectrogoniometers (e.g. 18,19). This would enable the investigation of accurate laser intensity (for, e.g., albedo studies) for snow, instead of the relative (qualitative change detection) approach presented in this paper. Even though the intensity data would not be useful by itself, it will complement the range data in laser scanner change detection algorithms, which are feasible even with relative calibration. It would also facilitate the use of calibrated intensity images produced by laser scanners. This study is a part of an ongoing development of laser scanner data interpretation algorithms that would utilise both (calibrated) reflectance and topographic information. In the future, such algorithms would be potential as *in situ* and remote environmental change detection tools that would find applications in, e.g., the validation of airborne and satellite-based snow monitoring (e.g. in Alpine and Boreal regions) as well as in detailed (terrestrial) snow cover change detection.

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REFERENCES

1 Danson F M, D Hetherington, F Morsdorf, B Koetz & B Allgower, 2007. Forest canopy gap fraction from terrestrial laser scanning. IEEE Geoscience and Remote Sensing Letters, 4: 157-160

2 Barber D M & J P Mills, 2007. Vehicle based waveform laser scanning in a coastal environment. In: The 5th International Symposium on Mobile Mapping Technology (MMT'07). Padua, Italia, 29.-31.5.2007. CIRGEO (Interdepartmental Research Center for Cartography, Photogrammetry, Remote Sensing and GIS) University of Padua

3 Hapke B, 1993. Theory of Reflectance and Emittance Spectroscopy. (Cambridge University Press) 455 pp.

4 Briese C, B Höfle, H Lehner, W Wagner, M Pfennigbauer, A Ullrich & C Doppler, 2008. Calibration of full-waveform airborne laser scanning data for object classification. In: SPIE Laser Radar Technology and Applications XIII, Orlando, 6950, 8pp.

5 Kaasalainen S, H Hyyppä, A Kukko, P Litkey, E Ahokas, J Hyyppä, H Lehner, A Jaakkola, J Suomalainen, A Akujärvi, M Kaasalainen & U Pyysalo, 2008. Radiometric calibration of LIDAR intensity with commercially available reference targets. IEEE Transactions on Geoscience and Remote Sensing, in press

6 Höfle B & N Pfeifer, 2007. Correction of laser scanner intensity data: data- and model-driven approaches. ISPRS Journal of Photogrammetry and Remote Sensing, 62: 415-433

7 Wagner W, J Hyyppä, A Ullrich, H Lehner, C Briese & S Kaasalainen, 2008. Radiometric calibration of full-waveform small-footprint airborne laser scanners. In: The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXVII (B1), Beijing 2008, 163-168

8 Kaasalainen S, A Kukko, T Lindroos, P Litkey, H Kaartinen, J Hyyppä & E Ahokas, 2008. Brightness measurements and calibration with airborne and Terrestrial Laser Scanners. IEEE Transactions on Geoscience and Remote Sensing, 46: 528-534

9 Arnold N S, W G Rees, B J Devereux & G S Amable, 2006. Evaluating the potential of high-resolution airborne LiDAR data in glaciology. International Journal of Remote Sensing, 27: 1233-1251

10 Höfle B, T Geist, M Rutzinger & N Pfeifer, 2007. Glacier surface segmentation using airborne laser scanner point cloud and intensity data. In: The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Espoo, Finland, Sep. 12-14, Vol. XXXVI, (Part 3 / W52), 195-200

11 Koltzow M, 2007. The effect of a new snow and sea ice albedo scheme on regional climate model simulations. Journal of Geophysical Research, 112: D07110

12 De Ruyter de Wildt M, G Seiz & A Grün, 2006. Snow mapping using multi-temporal Meteosat-8 data. EARSeL eProceedings, 5: 18-31
http://www.eproceedings.org/static/vol05_1/05_1_de-ruyter1.html

13 Prokop A, M Schirmer, M Rub, M Lehning & M Stocker, 2008. A comparison of measurement methods: terrestrial laser scanning, tachymetry and snow probing for the determination of the spatial snow-depth distribution on slopes. Annals of Glaciology, 49: 210-216
http://www.igsoc.org/annals/49/a49a123.pdf (last date accessed: 21.11.2008)

14 Kääb A, C Huggel, L Fischer, S Guex, F Paul, I Roer, N Salzmann, S Schlaefli, K Schmutz, D Schneider, T Strozzi & Y Weidmann, 2005. Remote sensing of glacier- and permafrost-related hazards in high mountains: an overview. Natural Hazards and Earth System Sciences, 5: 527-554

15 Wehr A & U Lohr, 1999. Airborne laser scanning – an introduction and overview. ISPRS Journal of Photogrammetry and Remote Sensing, 54: 68-82

16 Kaasalainen S, M Kaasalainen, T Mielonen, J Suomalainen, J I Peltoniemi & J Näränen, 2006. Optical properties of snow in backscatter. Journal of Glaciology, 52: 574-584

17 Kukko A, S Kaasalainen & P Litkey, 2008. Effect of incidence angle on laser scanner intensity and surface data. Applied Optics, 47: 986-992

18 Painter T H & J Dozier, 2004. Measurements of the hemispherical-directional reflectance of snow at fine spectral and angular resolution. Journal of Geophysical Research, 109(D24): 115

19 Peltoniemi J, S Kaasalainen, J Näränen, L Matikainen & J Piironen, 2005. The measurement of the directional and spectral signatures of light reflectance by snow. IEEE Transactions on Geoscience and Remote Sensing, 43: 2294-2304