TOWARDS AN AUTOMATED DETECTION OF AVALANCHE DEPOSITS USING THEIR DIRECTIONAL PROPERTIES

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ABSTRACT:

Snow avalanches killed more people in the Swiss alpine area during the past decades than any other natural hazard. To further improve the avalanche prediction and the protection of people and infrastructure, information about the occurrence and the distribution of avalanche activity is crucial. Nevertheless this information is missing for large parts of the Alpine area. The surface roughness of avalanche deposits differs considerably from the adjacent undisturbed snow cover and is an important factor of the directional reflectance anisotropy. The undisturbed snow-cover exhibits a strong forward scattering, while the structure of an avalanche deposit causes shadow casting and tilt effects. Therefore, the observed reflectance of avalanche deposits and undisturbed snow cover is strongly dependent on the illumination- and viewing angles. This study demonstrates the potential of multiangular remote sensing data for detecting and mapping avalanche deposits. The results indicate, that air- or spaceborne multiangular sensors are suitable for rapid detection and mapping of avalanches in inaccessible and remote regions.

1. INTRODUCTION

Snow avalanches are natural processes whereby deposited snow shifts to more stable positions. In Switzerland, snow avalanches are rather rare events but cause more causalities than any other natural hazard. During the past 10 years, 223 people died due to avalanches within Switzerland. During the winter seasons of 1996/1997 to 2005/2006 avalanches caused approximately 1020 fatal causalities within the European Alps (Schweizer, 2008). The Swiss Forum for Climate and Global Change predicts a precipitation increase of about 10% during the winter season and a significant increase in extreme weather events until the year 2050 in Switzerland (OcCC/ProClim, 2007). In higher elevations, larger amounts of snow and more extreme weather events are likely to increase avalanche activity. Due to intensified touristic use of Alpine areas, information about the changing threat from natural hazards is essential (Nöthiger and Elsasser, 2004).

Rapidly available and accurate information about the location and extent of avalanche events is important for avalanche forecasting, safety assessments for roads and ski resorts, verification of warning products, hazard mapping as well as for avalanche model calibration/validation (Gruber and Margreth, 2001; McClung and Schaerer, 2006; Purves et al., 2003). Today, the detection and mapping of avalanches mainly relies on point observations acquired by individual experts in the field. Consequently, the achieved coverage is rather poor as only events within a restricted region can be recorded. Quite often only avalanches that caused accidents or heavy damages are

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mapped. Large parts of the Alpine region are inaccessible for observers, especially if the avalanche danger level is high. No systematic detection and mapping of avalanches over large areas is carried out today. However, acquisition of such data would be important for verification purposes, e.g. for the independent assessment of the accuracy of avalanche reports Remote sensing instruments are able to acquire wide-area data without restriction due to poor ground accessibility. Nevertheless, no investigations have been carried out in regards of wide-area detection and mapping of snow avalanches. Isolated, disastrous events have been mapped using Quickbird optical satellite data (Huggel et al., 2005), helicopter based LIDAR data (Vallet et al., 2000) and ERS SAR data (Wiesmann et al., 2001), but none of the applied methods are adequate for an wide-area and operational mapping of large to small size deposits. This paper investigates the potential of multiangular, spatially high resolved optical remote sensing data for avalanche deposit detection and mapping.

2. DIRECTIONAL PROPERTIES OF AVALANCHE DEPOSITS AND THE ADJACENT UNDISTURBED SNOW COVER

In the majority of cases, avalanche deposits are composed of the same material as the adjacent snow cover. ASD spectroradiometer measurements of avalanche deposits and adjacent undisturbed snow cover reveal that a discrimination solely based on their spectral properties is not straightforward (Treichler et al., 2009). Observations in the field show that, dependent on the illumination and observation angles, avalanche deposits can appear darker or brighter than the adjacent undisturbed snow cover (Figure 1.). The explanation of this phenomenon is given by the bidirectional reflectance distribution function (BRDF) of avalanche deposits and adjacent undisturbed snow cover. The BRDF is an object inherent property that can be used to label objects based on spectro-directional data. Smooth surfaces such as water bodies in calm weather reflect the major part of the incoming radiance in a forward direction (sun glint). Rough surfaces such as canopy show differing BRDFs caused by object properties such as shadowing and tilt effects (Despan and Jacquemoud, 2004; Lucht, 2004).

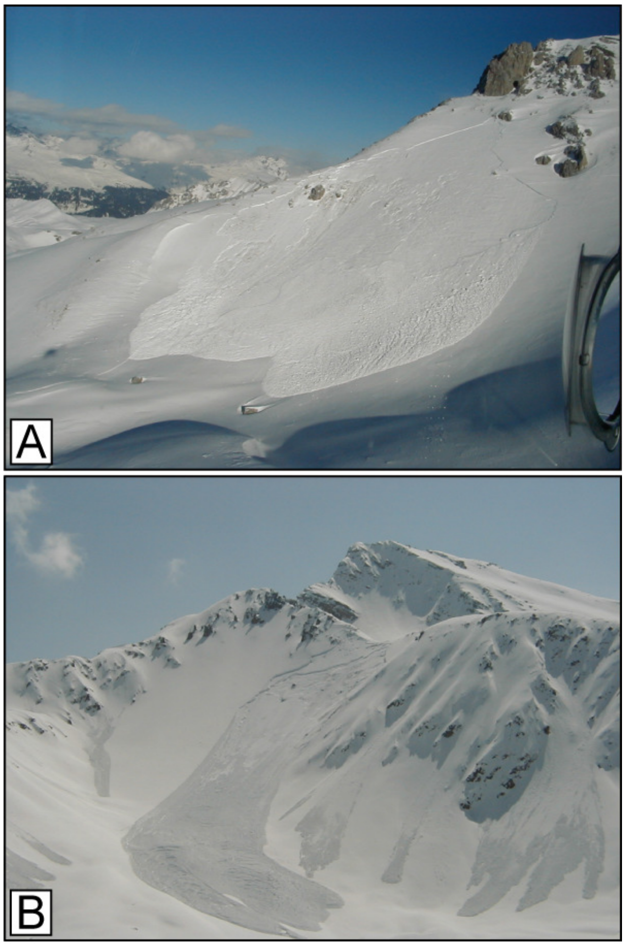

Figure 1. Slab avalanche deposits appearing brighter (A) and darker (B) than the adjacent undisturbed snow cover (photography © SLF, R. Meister)

Smooth snow surfaces show a strong forward scattering (Peltoniemi et al., 2005), while the rough surfaces of avalanche deposits cause a mosaic of clearly visible shadowed and strongly reflecting spots (Mushkin and Gillespie, 2005; Nolin and Payne, 2007). Dependent on the illumination and observing angles, a sensor measures different amounts of shadowed areas within the same avalanche deposit (Figure 2). These effects are most pronounced within the solar principal plane (PP), at large sun zenith angles and if the deposit is made up of large elements. The BRDF effects of avalanche deposits behave contrary to the forward scattering of the undisturbed snow cover. This explains the phenomenon illustrated in Figure 1.

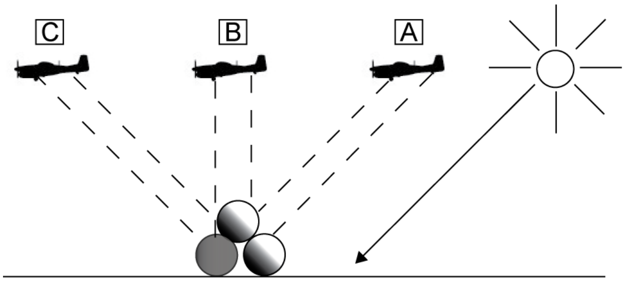

Figure 2. BRDF effects over avalanche deposits. Looking ahead, the sensor measures mainly the bright spots of the deposit (A). The nadir looking angle measures a mixture of bright and shadowed spots (B), looking backward, the sensor measures primarily the shadowed spots (C).

3. SENSOR ADS40

The airborne digital pushbroom scanner ADS40–SH52, built by Leica Geosystems AG, Heerbrugg, Switzerland, is able to acquire high spatial resolution imagery with a dynamic range of 12 bits in five spectral bands and three observation angles simultaneously (Figure 3). The radiometrically stable instrument belongs to a new generation of airborne sensors, aimed at replacing the analogue airborne cameras used for surveying and topographic mapping (Petrie and Walker, 2007). In Switzerland, the Federal Office of Topography (swisstopo) and Leica Geosystems operate ADS40 instruments. Due to the high spatial and radiometric resolution, the sensor is able to detect small variations within the snow cover even in shadowed regions and has therefore a big potential for the detection and mapping of avalanche deposits. The technical characteristics of the sensor are listed in 0. Due to optimization of the camera settings for the multispectral bands prior to the data acquisition, the panchromatic bands saturated and could not be used for this study. The available difference in looking angle was therefore constricted to 16°. Leica Geosystems preprocessed the data and geometrically calibrated it to a resolution of 20 cm. As such a high spatial resolution is not necessary for the detection and mapping of avalanche deposits and the big amount of data slows down the processing, the data was scaled to a spatial resolution of one meter, using a windowed sinc(x/a) resampling convolution kernel (Hore et al., 2007; Oppenheim and Schaeffer, 1975). Terrain induced illumination effects cannot be corrected due to the unavailability of a digital elevation model DEM with a spatial resolution comparable to the data from the sensor ADS40.

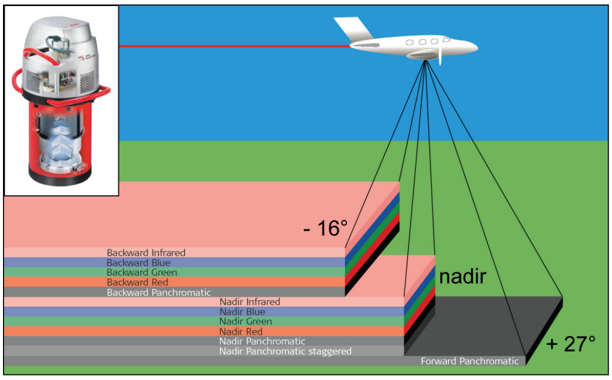

Figure 3. Viewing directions and associated spectral bands as used in this study (adapted from Leica, 2008); inset: and drawing of the ADS40–SH52

Focal length	62.7 mm
Total field of view (across track)	64°
Number of pixels across track	12'000
Spatial resolution	5 to 50 cm (dependent on flight level)
Radiometric resolution	12 bit
Spectral bands	blue: 428 – 492 nm green: 533 – 587 nm red: 608 – 662 nm NIR: 833 – 887 nm PAN: 465 – 680 nm (saturated)
Look~~ing~~ angles	blue: nadir, 16° backward green: nadir, 16° backward red: nadir, 16° backward NIR: nadir, 16° backward PAN: 27° forward, nadir, 16° backward (saturated)

Table 1. Technical specification of the ADS40-SH52 configuration used in this study (Leica, 2008)

4. METHODOLOGY

Based on visual image interpretation of the full resolution ADS40 data, samples of avalanche deposits and adjacent undisturbed snow cover were extracted from three test sites selected by comparable slope and aspect characteristics. The normalized difference angular index NDAI was calculated from near infrared bands with look angles nadir and 16° backward respectively (1). This approach produced good results for the approximation of surface roughness of snow and ice in Greenland using MISR data; the normalization removes pixel-to-pixel illumination differences (Nolin et al., 2002; Nolin and Payne, 2007). The values of the pixels were averaged within the sample area to reduce the influence of numerous outliners caused by the rough surface of avalanche deposits and minor inaccuracies of the geometric calibration.

$$NDAI = \frac{nir_A - nir_B}{nir_A + nir_B} \qquad (1)$$

where:
$NDAI$ = normalized difference angular index
nir_A = near infrared band that measures more shadow over the avalanche deposit (see Figure 2)
nir_B = near infrared band that measures less shadow over the avalanche deposit (see Figure 2)

Positive NDAI values indicate a forward scattering, which is expected for smooth, undisturbed snow surfaces. The rough surface of avalanche deposits is expected to show negative NDAI values.

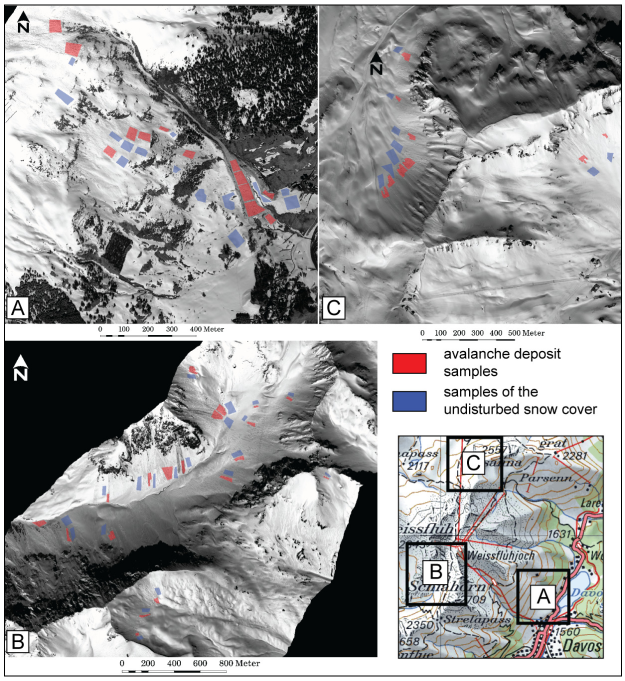

Figure 4 Spatial overview of the collected samples within the test sites Dorfberg (A), Haupter Taelli (B) and Casanna (C)

5. RESULTS AND DISCUSSION

The NDAI values of the avalanche deposit samples are clearly smaller than the values of the undisturbed snow cover samples. Though the observation angle difference of 16° is small, the samples from the test sites Dorfberg and Haupter Taelli show a good separability independent of their exposition (Figure 5, A & B). During data acquisition at 11:30 local time, the solar azimuth was 186° and the azimuth of the flight trajectories was 34°. The plane was flying away from the sun and the backward looking band measured a big fraction of shadowed spots within the avalanche deposits while the nadir looking band measured only few shadowed spots (see Figure 2). Within these two test sites, many large-scale wet snow avalanches occurred shortly prior to the data acquisition. Their mostly big deposition elements (more than 50 cm in diameter) cast large shadows, resulting in negative NDVI values.

The azimuth of the flight trajectory covering the test site Casanna is 214°. The plane was flying towards the sun, in the opposite direction than during the data acquisition over the first two test sites. In this case, the backward looking band records almost no shadowed spots within avalanche deposits (see Figure 2). As no forward looking band was available for this study, the nadir looking band is used as nir_A in equation (1). The separability of according NDAI values is clearly worse for the given flight direction because the nadir looking band records less shadowed fractions within avalanche deposits than the backward looking band during the data acquisition over the test sites Dorfberg and Haupter Taelli.

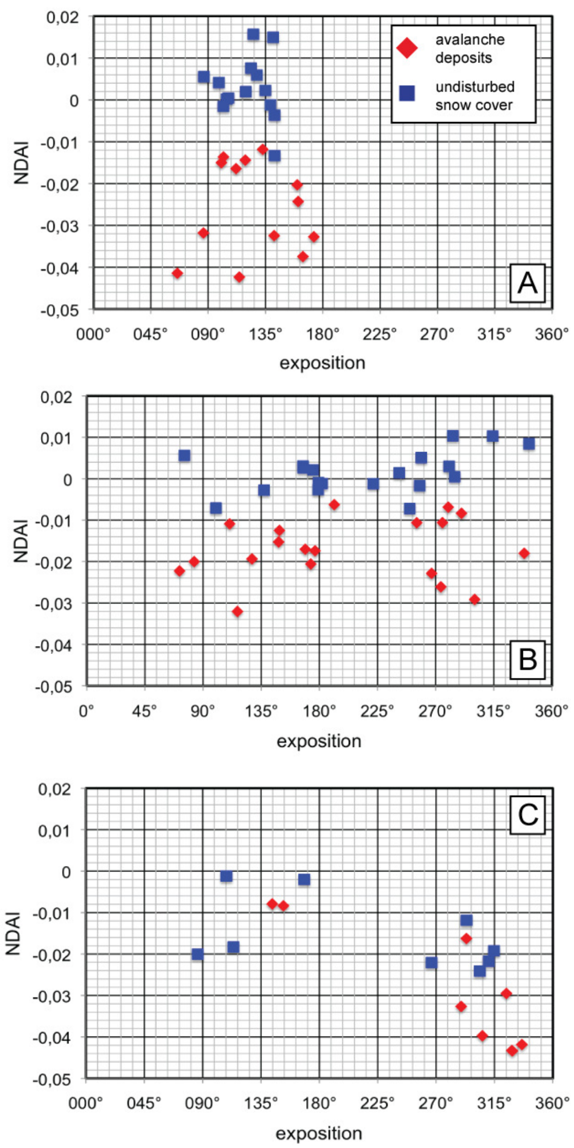

Figure 5 Distribution of NDAI values for samples dependent on the mean exposition for the test sites Dorferberg (A), Haupter Taelli (B) and Casanna (C)

Furthermore, the majority of avalanche deposits within the test site Casanna are loose snow avalanches with small deposition elements (less than 50 cm in diameter) that cause smaller shadowed spots. Therefore, the NDAI values of avalanche deposits are not clearly separable from the NDAI values of undisturbed snow cover (Figure 5 C).

6. CONCLUSIONS

The directional properties of avalanche deposits are contrary to the adjacent, undisturbed snow cover. While undisturbed snow cover shows a strong forward scattering, the rough surface of avalanche deposits scatters the main portion of the incoming radiance in a backward direction. Deposits with large elements show clearly stronger backward scattering than deposits consisting of small elements. Though the observation angle difference used in this study is very low (16°), avalanche deposit samples are well separable from undisturbed snow cover samples using the normalized difference angular index NDAI. The BRDF effects observed over disturbed and smooth snow surfaces are strongest in the solar principal plane. Because directional characteristics of smooth and rough snow surfaces get more distinct with larger sun zenith and observation zenith angles (Warren et al., 1998), we expect that a larger difference observation angle difference would strongly improve the results. A large sun zenith angle on the other hand causes cast shadows in Alpine terrain, constraining the analyzable area. To further investigate the potential of multiangular remote sensing data for wide-area avalanche deposit detection and mapping, the forward and backward looking panchromatic bands of the ADS40 should be analysed. (Bühler et al., 2009) show that an approach combining the described directional information with texture analysis and object-based labelling reveals a high avalanche detection rate and a good mapping accuracy. Spaceborne sensors with directional data acquisition capability such as

SPOT5, PRISM on ALOS or CHRIS on PROBA are also interesting tools for wide-area avalanche detection and their potential should be further investigated.

7. LITERATURE

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