

REMOTE SENSING TOOLS FOR SNOW AND AVALANCHE RESEARCH

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ABSTRACT: Since the first images acquired from airplanes (1915) and satellites (1960), remote sensing has had a great impact in diverse number of fields such as meteorology, military, topographic mapping, archaeology and forestry. Today remote sensing has even become a common tool for the general public, with location searches using high spatial resolution (< 1m) imagery on GoogleEarth or Bing Maps. The advantages are clear, remote sensing instruments can cover large spatially continuous areas without touching the ground. This is especially important for high-alpine terrain due to restricted accessibility. However, the application of remote sensing instruments in snow and avalanche research is limited. Important reasons for this might have been the low spatial and temporal resolution of past technology as well as the high costs for satellite imagery, which may have hindered successful and economic applications.

However, with advancing sensor technology capable of acquiring data with 12bit radiometric resolution and very high spatial resolution, such limitations are being addressed. Today, more than a dozen civil satellite sensors are operational, which are capable of acquiring data with a spatial resolution better than 5m as well as many airborne sensors with comparable characteristics. This paper presents an overview of the promising remote sensing applications for snow and avalanche research which apply the current sensor technology. We discuss potential applications such as digital elevation model DEM generation, avalanche detection, snow depth and snow type mapping, give a short overview past research in this field and show preliminary results from current projects at the SLF.

KEYWORDS: Remote Sensing, Digital Elevation Models DEM, snow depth, snow type, spatially continuous measurements.

1 INTRODUCTION

Avalanche terrain can generate challenging and complex morphologies. Steep slopes with danger from avalanches, rock fall or debris flows make most areas of interest partly or completely inaccessible. This is a major problem for practice and research since most measurements can only be performed at specific accessible but isolated points (e.g. weather stations, snow profiles, avalanche activity observations and so on). However, the snow pack characteristics can vary substantially with in close proximity to a measurement location (Schweizer et al. 2008).

Aerial and satellite remote sensing instruments are capable of acquiring spatially continuous datasets over large areas in otherwise inaccessible terrain. In combination with existing ground-measurement networks, such remote sensing methods can provide the important data to fill existing information gaps.

The application of remote sensing data to snow and avalanche research started with the availability of optical satellite imagery focusing on snow cover mapping (Tarble 1963; Rango & Ippen 1976). The investigations of Wiscombe and

Warren (1980) and Warren (1982) set the base for understanding the optical properties of snow. (Dozier 1989) used the Landsat TM satellite sensor to map Alpine snow cover. Imaging spectrometers (hyperspectral sensors) have enabled the investigation of snow surface properties according to changes in electromagnetic wavelength (Painter et al. 2003; Dozier and Painter 2004; Dozier et al. 2009). Shi and Dozier 1995, Strozzi and Mätzler (1998) as well as Nagler and Rott (2000) applied synthetic aperture radar SAR to map wet snow. Rees (2006) compile a good overview on remote sensing applications to snow and ice.

The majority of these investigations, however, use coarse spatial resolution data (> 30m) to cover large areas of several thousand square kilometers. But coarse resolution sensors have the disadvantage of recording many overlaying signals in one pixel (e.g. cast shadow, rocks, snow-free patches, different snow types) particularly in alpine areas with complex relief. In this paper, we focus on some applications of commercially available high spatial resolution optical sensors, which are promising for snow and avalanche research. We present some preliminary results from ongoing research in this field at the WSL Institute for Snow and Avalanche Research SLF.

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2 DIGITAL ELEVATION MODELS DEM

Digital elevation models DEM, a collective term for digital surface models DSM and digital terrain models DTM are the basis for many different applications such as characterising terrain morphology (elevation, slope, aspect, curvature, roughness etc.) or the numerical simulation of avalanches, (Christen et al. 2010; Sample and Zwinger 2004). Current technology such as airborne laser scanning LiDAR, Vosselman and Maas (2010) or digital photogrammetry, Linder (2009) enable the generation of high-quality DEM datasets with fine spatial resolution (< 5m). Bühler et al. (2012) demonstrated that detailed DEM resolutions can be achieved even in complex alpine terrain with high accuracy (Fig. 1). Such a detailed spatial resolution is required to capture relevant terrain features such as gullies, ridges or rocks. The applications in snow and avalanche research for such fine resolution and spatially ranging DEM datasets are numerous. Maggioni and Gruber (2003) and Bühler et al. (in preparation) apply geomorphometry to detect avalanche release areas. Bühler et al. (2011a) and Feistl et al. (2012) perform numerical simulations of large to small scale avalanches. Mass balance investigations of avalanche release and deposition zones are conducted, enabling energy balance and snow metamorphism modeling (Bartelt and Lehning 2002), which assist hazard mapping and zoning. In the future a systematic coverage of alpine areas with summer and winter DEMs, which are frequently updated, will serve to advance the current application in research and practice facilitating spatially better resolved and therefore more precise investigations.



Figure 1: 3D view of a high spatial resolution DEM (0.5m, hillshade) from the SLF Vallée de la Sionne test site, Canton Vallais, Switzerland

3 SNOW DEPTH MAPPING

The depth of the snow cover and the extent to which new snow cover is redistributed are spatially and temporally highly variable and are crucial parameters for the formation of avalanches. However, to date these parameters are only measured punctually by isolated automated weather stations or observers. Remote sensing instruments are capable of acquiring snow depth data over large spatially continuous areas. Terrestrial laser scanning has already proven its ability to monitor the spatial distribution of snow depth in subsets of single Alpine catchments, (Prokop 2008; Grünwald et al. 2010; Egli et al. 2012). While even though terrestrial laser scanning can cover large areas, it is still restricted to single catchments within distances below 5 km which lie in the line of sight of the sensor. Airborne or spaceborne sensors on the other hand can cover several hundreds of square kilometers in one data acquisition. A current project at the SLF investigates the potential of airborne digital photogrammetry to derive precise snow depth measurements calculated from summer and winter DSMs. We use airborne and terrestrial laser scanning and field measurements as reference data. Preliminary results indicate that snow depth measurements with a precision of 20cm can be obtained, which are confirmed with hand measurements (Bühler et al., 2011b).

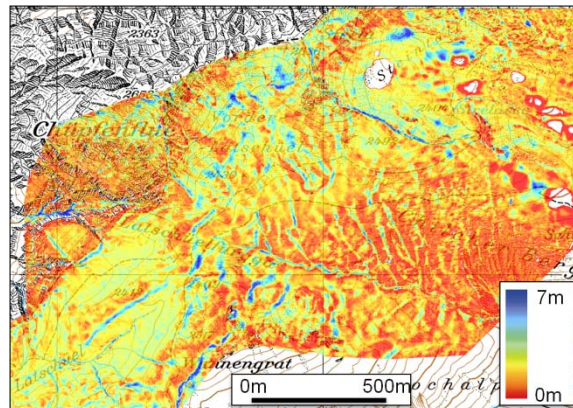


Figure 2: Spatially continuous mapping of snow depth distribution derived from summer and winter DSM based on digital photogrammetry (Bühler et al. 2011b)

4 AVALANCHE ACTIVITY MAPPING

A major problem for avalanche warning, in addition to planning avalanche mitigation measures, is the lack of information on recent and historic avalanche events. In Switzerland, a dense network of approximately 180 observers gathers data on recent avalanche events in the field (SLF 2012), while large portions of Alpine terrain are poorly covered since they are inac-

cessible and hazardous. This is especially the case during bad weather periods, when current avalanche information is most crucial; but no data can be acquired by observers. Here, remote sensing can provide additional information to close these gaps.

Using airborne or spaceborne opto-electronic scanner data, recent avalanche deposits can be mapped with high accuracy over large areas (Bühler et al. 2009, Lato et al. 2012), which is a big help to gather information on avalanche activity and to build and update avalanche databases (Fig. 2). However, during bad weather conditions such as snow fall or cloud covered skies, optical sensors are not able to acquire data.

Radar sensors with high spatial resolution on the other hand are able to acquire data through clouds, during night and even during precipitation. High spatial resolution spaceborne sensors such as TerraSAR-X, Cosmo-Skymed or Radarsat-2 have great potential for this purpose (Wiesmann et al. 2001). To date issues such as layover, foreshortening or radar-shadow, which are most distinct in steep terrain, hindered successful applications in this field. There is a need to further investigate and validate the applicability of SAR technology for avalanche mapping.

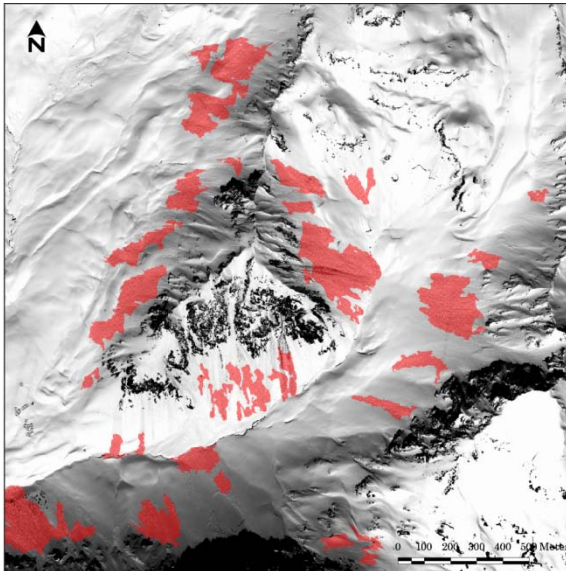


Figure 3: Automated identification and mapping of recent avalanche deposits (in red) based on airborne opto-electronic scanner data (Bühler et al. 2009).

5 SNOW SURFACE TYPE MAPPING

Due to the high sensitivity of near infrared wavelength, especially around $1 \mu\text{m}$ (Warren 1982; Dozier et al. 2009), optical remote sensing instruments can be used to map the different optical equivalent diameters at the snow surface. Exploiting these properties, relevant snow

types such as windblown snow (very small compact grains), ice crusts (big grains) and snow containing free water can be well distinguished (Dozier et al. 2009). Because the snow types at surface show large variability even over small distances, high spatial resolution instruments have great potential to map snow surface type and characteristics.

If this can be successfully realised, it would provide a powerful tool for avalanche warning services, if for example areas covered by surface hoar could be mapped before new snow is falling or ice crusts with poor bonding characteristics could be delineated. Many commercially available spaceborne and airborne remote sensing instruments are equipped with a near infrared band (wavelength around $0.9 \mu\text{m}$). First investigations at SLF (Fig. 4) demonstrate great potential to use commercial remote sensing instruments for snow type mapping (Raymann 2010; Bühler et al. 2011c). A large drawback of this methodology is that only the surface cover can be investigated.

High spatial resolution SAR sensors on the other hand are able to penetrate dry snow-surfaces and to gather information on different snow layers as long as there is now free water in the snowpack (Rott and Mätzler 1987; Mitterer et al. 2011). But the radar signals reflected from different layers within the snow cover are not yet fully understood. Future research is required to assess the potential of radar to map weak layers.

5 CONCLUSIONS

A large variety of remote sensing sensors are available today. In particular the spatial resolution of commercial sensors, their number and therefore the availability (temporal resolution) has improved substantially during the past decade. Regardless of the challenges faced for remote sensing applications due to steep and complex alpine terrain (Buchroithner 1995), current air and spaceborne sensor systems with high spatial and radiometric resolution are able to generate spatially continuous information on crucial snow properties.

While the potential is great, the application of these new remote sensing capabilities lack scientifically sound validation. The collation of appropriate ground reference datasets in alpine terrain is a major challenge in this respect, especially during wintertime. Preliminary investigations and tests performed at SLF are revealing the potential of remote sensing technology to close information gaps which result from measuring parameters at isolated points. Successful remote sensing systems cannot be expected without representatively distributed ground ref-

erence datasets. A prerequisite for remote sensing systems is a clear and careful validation of the user products in addition to clear communication of its limits and uncertainties. This will strengthen the confidence of snow and avalanche practitioners in current remote sensing technology and set the base for the development of successful new services.

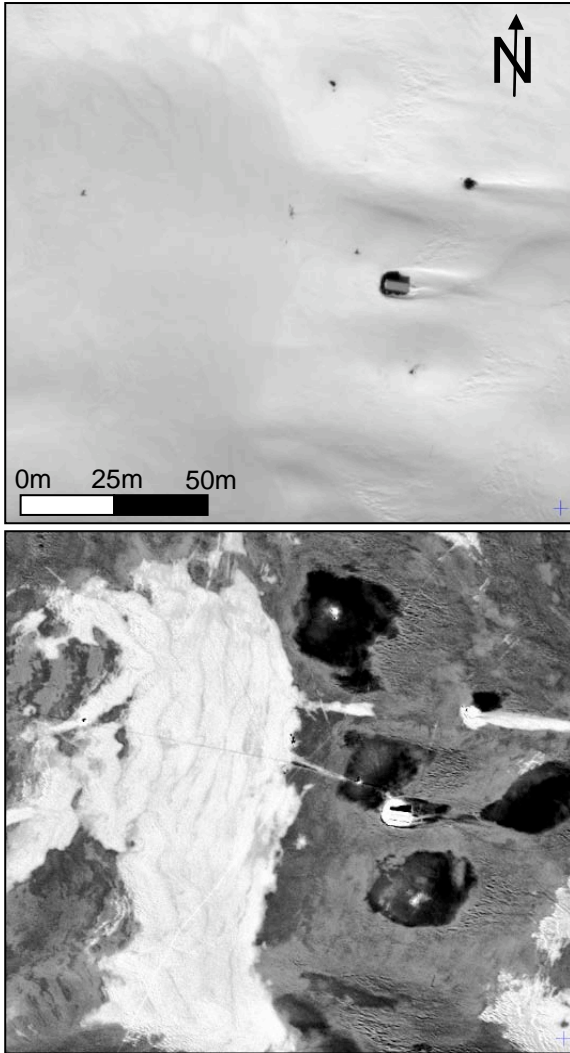


Figure 4: The same subset of an ADS40 opto-electronic scanner image in the blue band (top) and a near infrared index (bottom). Different snow types can be clearly identified using near infrared information.

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