MEASURING SNOW DEPTH WITH A TERRESTRIAL LASER RANGING SYSTEM

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ABSTRACT: Knowledge on the spatial and temporal distribution of snow depth is one of the key parameter in the assessment of avalanche hazards, for snow drift and avalanche modelling and model verification. Reliable measurements of snow depth distribution are of interest for practitioners as well as for scientists. Most of the conventional methods like snow pits, probing or profiling deliver point information or transects of snow depth, snow density or snow water equivalent. At that, direct (in situ) measurements are chancy in High Alpine terrain. To overcome these restrictions, remote monitoring techniques are applied. Terrestrial scanning lidar survey represents a powerful tool to map inaccessible alpine terrain. In winter 2005/2006 numerous measurements with the terrestrial scanning lidar have been done at the test site in the Wattener Lizum (Tyrol, Austria). The analysis of the repeated surveys provide changes in the depth of the snow cover.

KEYWORDS: TSL, Terrestrial Scanning Laser, remote sensing, snow depth distribution

1. INTRODUCTION

In opposition to conventional methods remote monitoring techniques, like TSL (terrestrial scanning laser), enable observations with high spatial and temporal resolution from a save distance. Application of TSL cover a large field, like scanning architecture (Pfeifer and Rottensteiner, 2001), topography, landslides and glaciers (Deline et al., 2004).

By contrast the use of a laserscanner in snow and avalanche research is rare, up to now only a few projects have been carried out. The goal of the project SAMPLE (Snow Avalanche Monitoring and Prognosis by Laser Equipment) was the remote sensing of snow depth in order to advance avalanche forecasting tools (Moser et al., 2001). Recently a joint project has been carried out in Lech am Arlberg (Vorarlberg, Austria), where the BFW (Federal Research and Training Centre for Forests, Natural Hazards and Landscape) own laser scanner is used for snow depth measurements (Prokop, 2005).

The following section gives a description of the laser equipment and an impression of the test site. In section 3 the accuracy of the laser is verified and measurement results from significant time periods are analysed. Conclusions and an outlook of the further use of TSL within the EU (European Union) funded GALAHAD project are given in section 4.

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2. INSTRUMENT AND TESTSITE

2.1 Instrument

Laser principle is similar to that one of ordinary radar, except that lidar systems send out narrow pulses or beams of light, rather than broad radio waves. Wavelengths used in lidar depend on the application and extend from about 250 nm to 11000 nm, corresponding to a range from UV to IR (Weitcamp, 2005).

All surveys at the testsite were done with the long-range Laser Profile Measuring system LPM-i2K, including the software RiProfile from RIEGL (manufacturer, www.riegl.com). Figure 1 gives an overview of the technical data.

Laser wavelength λ	905 nm (near IR)
Measuring range [1)]	
good refl.coeff.(ρ≥0.8)	up to 2500 m
bad refl.coeff. (ρ≥0.1)	>800 m
Reflecting foil	2500 m
Accuracy	typ. +/- 5 cm
Measuring time	0.25 up to 1 s
Beam divergence [2)]	1.2 mrad (0.0688°)
Pulse duration approx.	11 ns
Scanning range	horizontal: 360° vertikal:-20° / +130°
Pulse frequency	5 kHz
Weight	approx. 14.6 kg
Power supply	11-28 V DC
Temperature Range	
Operation Storage	0 °C to +50 °C -20 °C to +70 °C

[1)] depending on the reflection coefficient ρ of the target. In bright sunlight the operational range is considerably shorter, than under an overcast sky. At dawn or at night the range is even higher.
[2)] 1 mrad corresponds to 10 cm beamwidth per 100 m of range

Figure 1: Technical Data of RIEGL LPM-i2K (RIEGL, 2005 and RIEGL, 2006)

Laser ranging is based on measuring the time-of-flight of a short laser signal from the instrument's transmitter, to the target, and back to the receiver. For Riegl instruments the laser signal is pulsed and thus, the time-of-flight is evaluated by measuring the time interval between two short laser pulses, the transmitted pulse and the received pulse. According to a pulse frequency of 5 kHz (Figure 1), at most 5000 pulses can be emitted per point. The range to the target, R, is subsequently calculated from the time-of-flight, τ, according to

$$R = c_g \tau/2. \quad (1)$$

Where c_g is the speed of light of the optical transperent medium the laser pulse is propagating in (Ulrich, 2005).

The laser scanner records the range, the corresponding angles (azimuth and zenith) and the reflection coefficient ρ for each point (polar coordinates). ρ describes how much light is scattered into the backward direction and is defined by the ratio received intensity to transmitted intensity. In a predefined window, with a favoured resolution, the laser scanner executes all point measurements, separated by stepwise movements of the optics.

According to the aperture angle of the laser beam (1.2 mrad), Figure 3 gives a overview of the areal extent A of the footprint on the slope, dependent on the distance. The incident angle ϴ is defined as the angle between the axis of the laser beam and the normal vector **n** of the surface (Figure 2). In case of ϴ = 0 the laser beam hits the ground perpendicular and the footprint is a circle. With increasing ϴ the illuminated area arises and turns into a prolate elliptic shape. Certainly some parts of the slope can be additionally inclined to other directions (couloir, gully, etc.). To simply matters, this point is excluded here, so the values in the Figure 3 can be considered as minimum. The significant distance in our target region, from 500 to 1500 m, is typed in bold letters (Figure 3).

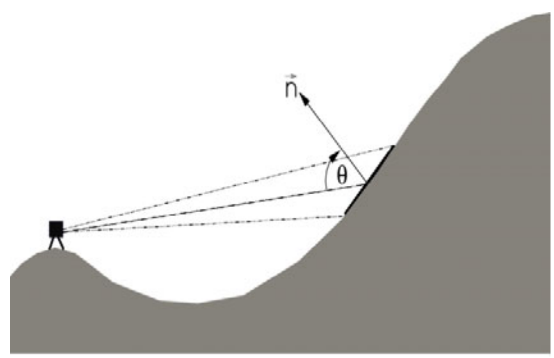

Figure 2: Definition of incident angle ϴ and normal vector **n** of the surface.

ϴ	**A 500m**	**A 1000m**	**A 1500m**	A 2000m	A 2500m
[°]	**[m²]**	**[m²]**	**[m²]**	[m²]	[m²]
0	**0.3**	**1.1**	**2.5**	4.5	7.1
60	**0.6**	**2.3**	**5.1**	9.0	14.1
65	**0.7**	**2.7**	**6.0**	10.7	16.7
70	**0.8**	**3.3**	**7.4**	13.2	20.7
75	**1.1**	**4.4**	**9.8**	17.5	27.3
80	**2.5**	**10.9**	**22.8**	40.5	63.3

Figure 3: Area A [m²] of the footprint on the slope, depending on different ranges and different incident angles ϴ.

Figure 4 points out a sharp increase of A above 75° incident angle. Generally high incident angles lead to lower backscattered radiation.

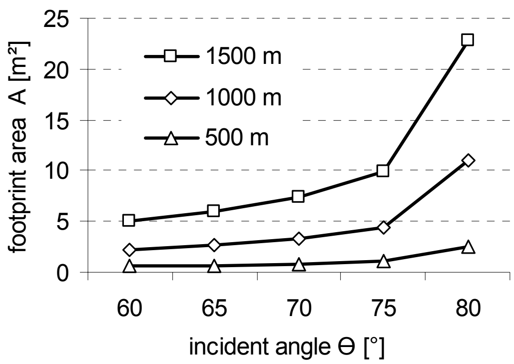

Figure 4: Plot of incident angle Θ versus footprint area A of the laser beam, depending on different ranges (500 to 1500 m).

Experiments demonstrate that no significant penetration of the laser beam into the snowpack occurred, i.e. the signal was reflected on the surface, as requested (Prokop, 2005).

As mentioned above (Figure 1) in bright sunlight the operational range is considerably shorter than under an overcast sky. In the case of intense illumination of the surface, the laser receives a strong signal over the whole solar spectrum, hiding the narrow laser pulse at near infrared. By contrast at dawn or at night reflection coefficients are uniformly strong, and the measurement range of the instrument is even higher. In case of precipitation (rain or snowfall) or droplets/iceparticles in the air (clouds, fog, snow drift) the laser signal suffer from strong absorption and scattering effects, and so measurements fail. If the reflection coefficient under-run a certain threshold, the laser software refer to as invalid measurement point.

2.2 Testsite

The testsite is located in the Wattener Lizum about 20 km south-east of Innsbruck (Tyrol, Austria). The advantage of this location is the infrastructure provided by the Austrian army, which runs a training camp there. Apart from that the undisturbed alpine terrain and the good reachability were the main reasons for choosing the Wattener Lizum as test site for the EU (European Union) founded project GALAHAD. The TSL is mounted on a concrete basement, which is also used by a ground-based synthetic aperture radar (GB-SAR), from University of Florence (Italy). Further two weather stations provide continuous measurements during winter. Figure 5 gives an overview of the instrumentation in the target region, a northeast orientated slope between the pinnacles of Tarntaler Koepfe (2767 m) and Lizumer Boeden (approx. 2020 m) in the bottom of the valley.

In order to protect the laser scanner against harsh weather conditions, the instrument must be removed in case of non-use. Six targets (tie points) have been mounted on rocks, their exact positions have been determined by a surveyor. These 30x30 cm supported aluminium slabs, pasted up with a reflecting foil, are necessary for orientation of the instrument.

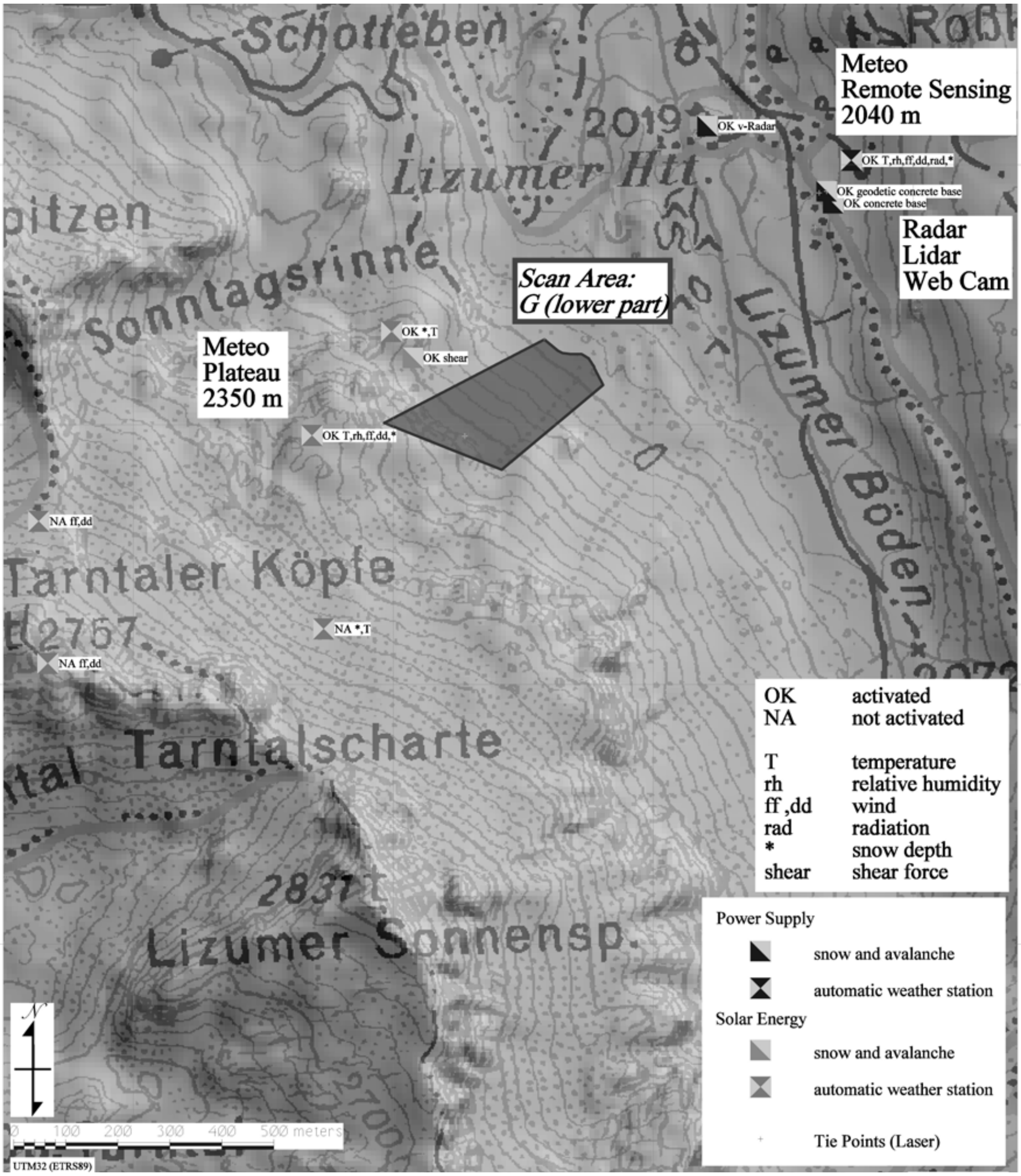

Figure 5: Map showing the target region with the instrumentation. The black frame marks the section for the analysis of snow depth changes.

3) RESULTS

3.1 Accuracy

The set-up of the laser always includes a scan of the targets with high resolution in order to calculate the actual position of the instrument. During the period December 2005 till July 2006 twenty four of these set-up measurements were done, range and reflection coefficients ρ of 6 tie points were determined in each case (Figure 6). High reflection coefficients result from nearby tiepoints (i.e. TP1, which is close to the basement). Vice versa decreasing reflection coefficients are measured at long distances (i.e. tiepoint TP6).

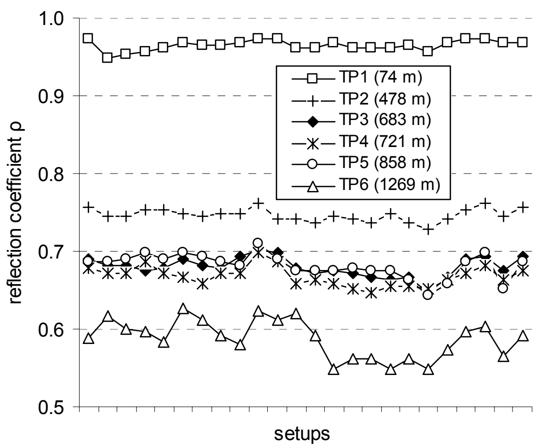

Figure 6: Reflection coefficients ρ of different tiepoints in 24 setups.

Median, maximum, minimum and the 25% and 75% quartiles display the variability of the distance measurements, the highest deviation was +/- 4 cm (Figure 7).

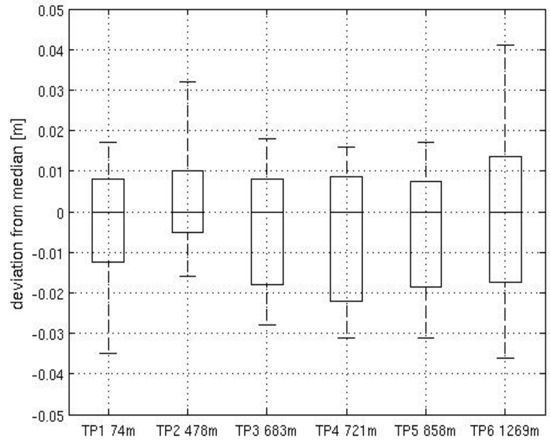

Figure 7: Maximum, Minimum, 25% and 75% quartile of the 6 tiepoints, relative to the median (=0).

3.2. Case studies

For each scan the laser software transform the measured polar coordinates (range, azimut angle, zenith angle) into Cartesian coordinates (UTM zone 32 north). This transformation is only feasible, if the accurate positions of several tiepoints are available.
The point cloud of each scan was subsequently converted onto a regular grid (3x3 m), using the Inverse Distance method. The difference of two single scans indicates the change in depth of snow cover, caused by wind, precipitation and settlement.

First case: Snow depth difference between 14.02.2006 and 21.02.2006

The period between February 14 and 21, 2006 was dominated by strong winds from south (foehn). The main wind direction is SSE, with gusts up to 17 m/s (Figure 8). In the evening of the 18 February, the foehn period was interrupted by a cold front passage, responsible for the observed snow depth increase of approximately +20 cm (Figure 8). Wind direction changed to north with decreasing wind speed. A photo of the target area is shown in Figure 9. On the bottom of the slope big scours near boulders are visible. On February 20 a spontaneous avalanche occurred in vicinity of the target region.

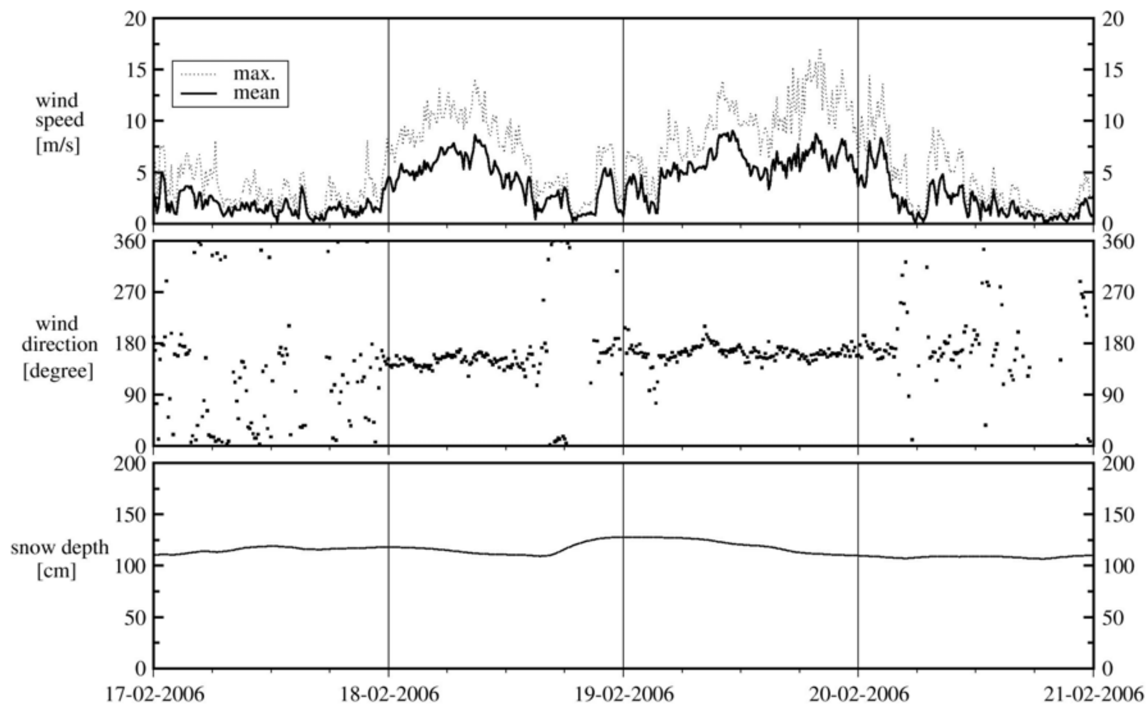

Figure 8: Snow and wind conditions during the foehn event, recorded by the lower weather station (Meteo remote sensing, 2040 m).

Figure 9: Photo of the testsite a few days after the foehn event (21.02.2006).

Figure 10 illustrate changes in the depth of snow cover between February 14 and 21, 2006. The section corresponds to the region indicated in Figure 5. Dark parts belong to an increase of the snow depth, bright areas to a reduction (Figure 10).

The strong wind blows off all ridges and fills the gullies, even if they were flat, visible in the pronounced black stripes. Summing up it may be said, that the mix of snowfall and wind leads to a marked change in the snow cover distribution, during the 7 day period.

Second case: Snow depth difference between 16.03.2006 and 16.05.2006

After several snowfall events the snow depth maxima at the upper weather station (Meteo Plateau, 2350 m) was achieved at the end of April. The following period is characterized by a continous settlement of the snow cover all over the slope, mainly due to increasing radiation. The strongest reduction occurred along a south-east facing gully wall, visible as a white strip (Figure 12). The permanent accumulation of snow in this part during winter is evident, also appearent in the first case (Figure 10). The central part of the investigation area (north-east aspect) is less distinctive. Consequently the total amount of snow melt is lower and more homogeneously distributed. Whereas in Figure 9 (21.02.2006) all boulders in the slope are covered by snow, these boulders are uncovered in the mid of May (see arrows in Figure 11). Areas protected from sun (north-west slopes) are characterized by moderate snow depth reduction (dark grey parts in Figure 12).

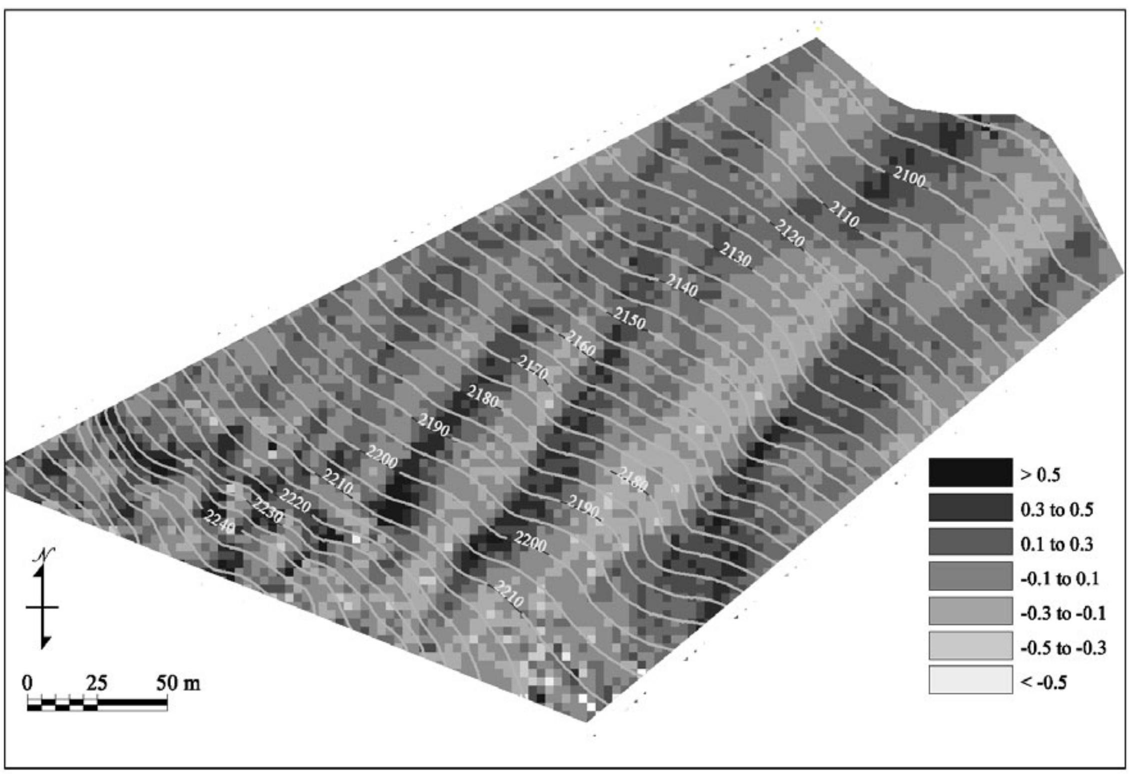

Figure 10: Snow depth changes [m] between February 14 and 21, 2006. Contour lines [m a.s.l.] of a digital elevation model are added.

Figure 11: Webcam following the growing of snow-free parts at the test site (16.05.2006).

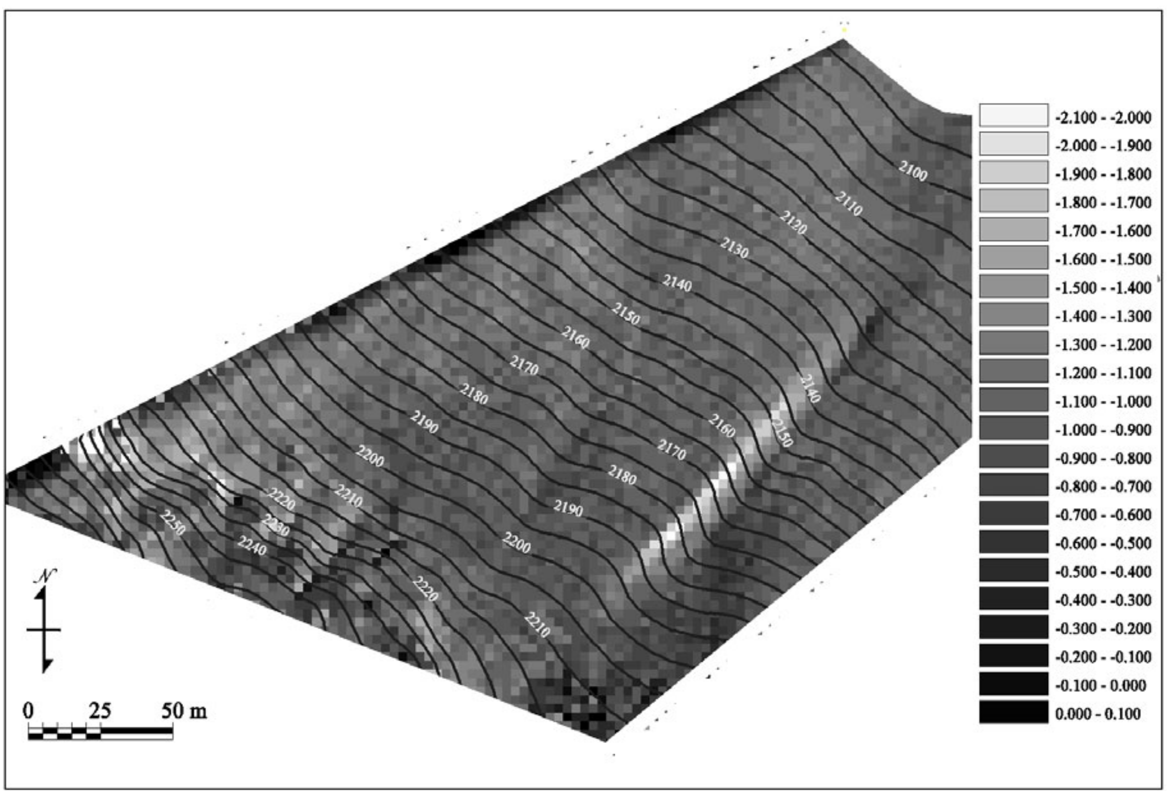

Figure 12: Changes in the depth of snow cover [m], between March 16 and May 16, 2006. Contour lines [m a.s.l.] of a digital elevation model are added.

4) CONCLUSION

The EU (European Community) founded project GALAHAD deals with innovative remote monitoring techniques for glaciers, avalanches and landslides. The goal of the avalanche related part is to verify the capability of different remote monitoring techniques (TSL, GB-SAR) on snow surface. The main tasks are the determination of the spatial snow depth distribution and the estimation of snow water equivalent.

The results from winter 2005/2006 (shown in chapter 3) are promising. Final detailed analysis with comparable methods (i.e. ultrasonic snow sensor, manual measurements) are lacking at the moment. An essential reliable reference digital elevation model is already in preparation, but not finished yet. Snow accumulation as well as snow erosion/ablation can be measured with the described TSL setup. The spatial and temporal resolution provided by the laser scanner is in a reasonable range. In the frame of snow and avalanche research a spatial resolution of about 0.1 m seems to be sufficient.

The TSL-instrument can be mounted on a tripol and easily positioned everywhere in the field. In comparison to other area based techniques (Photogrammetry, airborne laser scanning, GB-SAR, spaceborne-SAR) an affordable laser scanner represents a good alternative for flexible surface modelling. The laser scanner turns out to be a good instrument for researchers (e.g. estimation of avalanche release area from the opposite slope). Because of the incapability of TSL to measure in bad weather conditions and the long time period necessary for image acquiring the operational application (e.g. avalanche forecasting) is restricted.

5) ACKNOWLEDGEMENTS

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