REMOTE-SENSING DERIVED AVALANCHE INVENTORY DATA

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ABSTRACT: Every year snow avalanches pose a significant threat to transportation infrastructure. The societal demand to minimize closures of the main transport network while maintaining an acceptable level of personal safety at the same time has dramatically increased over the past decade. In Norway, decisions regarding avalanche warning, including pre-emptive road closure, are based on factors such as snow depth, meteorological conditions and expert opinion. The ability to automatically identify snow avalanches using very-high resolution optical imagery would greatly assist in the development of highly accurate, widespread, detailed maps of zones prone to avalanches. This would provide decision makers with better knowledge of previous events and details regarding the size and extent of historical events. We present the results of a 'proof-of-concept' study on the operation of a service providing the Norwegian Public Roads Administration (NPRA) with satellite data derived avalanche inventory data. We have explored the use of imagery from high-resolution and very-high-resolution space-borne satellites by developing and testing automated image segmentation and classification algorithms for the detection and mapping of avalanche deposits.

1. INTRODUCTION

In Norway, avalanches or high avalanche danger levels are regularly the cause of temporary closures of important national transport corridors. Over the last ten years pressure on the authorities has increased to keep road closures to a minimum while keeping the safety of the transport corridors at an acceptable level. Due to the size of the Norwegian road network, daily avalanche forecasts during wintertime are issued for specific sections only. To avoid or minimize the impact of avalanches on life and property, authorities, such as the Norwegian Public Roads Administration (NPRA) mandate preventative closures of individual sections of the transportation network. The decisions underlying the mandate are mainly based on meteorological forecasts, snow-cover observations and expert knowledge. For this purpose NPRA is dependent on reliable avalanche forecasts.

The validation of avalanche forecasts can be achieved using several methods and tools, one proven method being through the observation of occurred avalanches. However, monitoring vast regions for avalanches or critical snow conditions from ground and air is costly and difficult. Therefore, snow cover observations and avalanche mapping using satellite-based remote sensing has a large potential. The area covered by remote sensing approaches can be regional to local and stretch over areas where in-situ measurements are both difficult and time-consuming, or areas that are not accessible for in-situ observations at all.

2. POSSIBLE FUTURE SERVICE EMPLOYING SATELLITE DATA

The primary goals of the here presented pilot study were: (a) to automatically detect and map avalanches using optical remote sensing imagery; (b) to provide the NPRA with avalanche inventories derived by these algorithms, (c) to explore if such inventories could be provided shortly after major avalanche events; and (d) to test if such procedures could be streamlined within an operational service.

A possible service structure is schematized in Figure 1, with its flows of request, data and work between end-user(s)/subscriber(s), service provider and satellite-data provider(s). It is envisaged that such a service would work in two

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different operating modes: an ‘inventory mode’ and an ‘emergency mode’. The ‘inventory mode’ of the service is defined as an operational mode providing regular updates on the regional avalanche activity (decrease/increase) on pre-defined time intervals (e.g., every fortnight, monthly), defined on the basis of a subscriber’s needs. Information on the size of the avalanche, the run-out length, the avalanche type (slab, loose snow, point release, etc.) are of interest. Also the amount of snow (volume) and the wetness of the snow are of importance. Such information would have to be extracted from non-optical imagery, however, for example from Synthetic Aperture Radar (SAR) data.

The aim of an operational ‘emergency mode’ would be to provide subscribers with near real-time generated avalanche maps during critical avalanche situations or after that avalanches led to blockings of the transport network (roads, railroad).

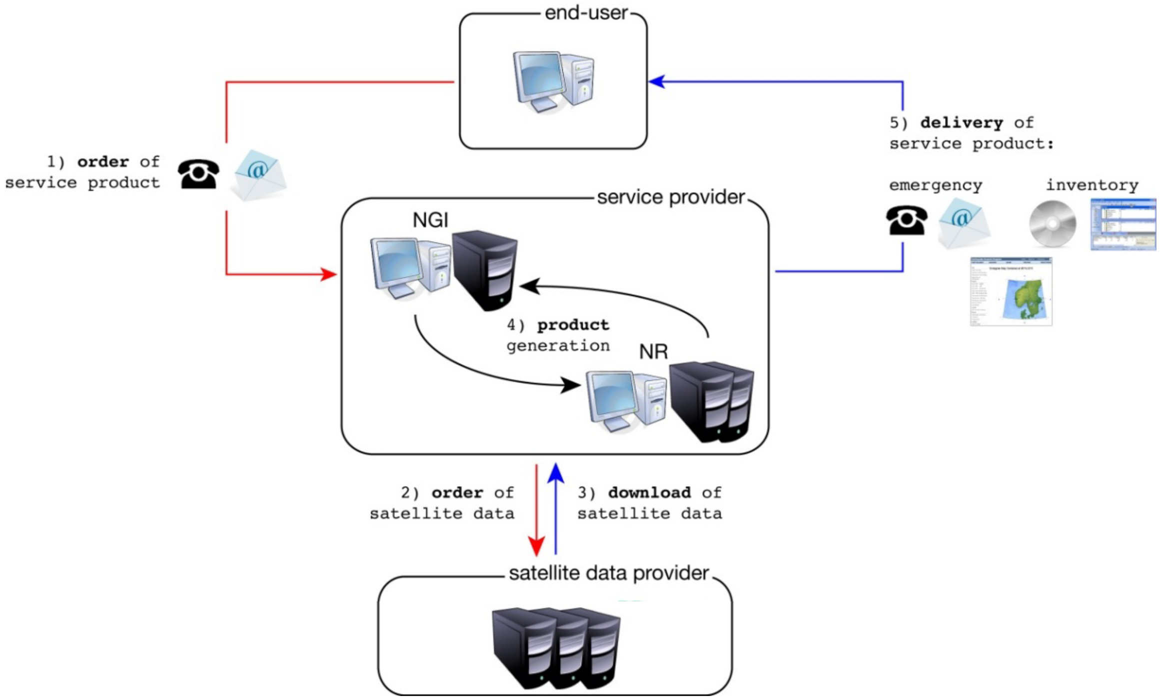

Figure 1: Schematized overview of the service architecture with its flows of request, data and work between end-user(s), service provider and satellite-data provide: (1) Service initiation through order submission by end-user/subscriber to service provider; (2) ordering of most feasible satellite data by service provider from satellite data provider; (3) download of ordered satellite data; (4) product generation by service provider; (5) delivery of service product by service provider to end-user/subscriber in pre-defined format.

3. DATA: SENSORS AND ACQUISITIONS

We explored the use of high-resolution (HR) imagery collected by the SPOT-2 and SPOT-4 satellites, of very-high resolution (VHR) imagery collected by the QuickBird satellite, and of a VHR airborne camera ADS40 SH52 (from Leica-Geosystems). Data from a total of nine test areas were explored (cf. Table 1).

The data was analyzed on an iterative basis: In a first step, HR SPOT-2/-4 multi-spectral data from the Tyin area, Central Norway, was explored. Secondly, we looked at panchromatic HR data from SPOT-4 from the Otta area, Central Norway. Finally, five sets of VHR QuickBird data and one set of VHR ADS40 data were analyzed. Four of these test areas were located in Norway and two in the Swiss Alps. All QuickBird data used was processed using the panchromatic band, due to its higher spatial resolution (0.6 m) as compared to the multispectral bands. Table 1 gives an overview of the main characteristics of the explored imagery.

Table 1: Main characteristics of the analyzed satellite imagery.

No.	**Region**	**Country**	**Mission**	**Sensor**	**Product**	**Pixel res. (m)**	**Acquisition date**
1	Tyin	Norway	SPOT-2	HRV	Mul20mX	20	2008-02-12
2	Tyin	Norway	SPOT-4	HRVIR	Mul20mI	20	2008-02-15
3	Otta	Norway	SPOT-4	HRVIR	Pan10mM	10	2008-02-15
4	Hellesylt-1	Norway	QUICKBIRD	QB02	PAN_MS1	0.6	2005-04-03
5	Hellesylt-2	Norway	QUICKBIRD	QB02	PAN_MS1	0.6	2005-04-16
6	Dalsfjorden	Norway	QUICKBIRD	QB02	PAN_MS1	0.6	2005-04-03
7	Eikesdalsvatnet	Norway	QUICKBIRD	QB02	PAN_MS1	0.6	2011-04-13
8	Val Gronda	Switzerland	QUICKBIRD	QB02	PAN_MS1	0.6	2009-02-25
9(*)	Davos area	Switzerland	ADS40 SH52	ADS40	B,G,R, NIR	0.2	2008-04-26

(*) cf. Bühler et al. (2009) for more information on the Davos dataset

4. METHODS AND RESULTS

4.1 Detection of avalanches in HR optical satellite data

Tyin test case: Between 24.1. and 26.01.2008 several large avalanches blocked large sections of a major regional road (‘Fylkesvei’ Fv53) for several days. Ancillary data for this event was available from a helicopter flight undertaken by the NPRA shortly after the event. Post-event multi-spectral data from SPOT-2 and SPOT-4 was available for the dates of 12.02.2008 and 15.02.2008 (cf. Table 1). The imagery was geo-referenced and integrated into a Geographical Information System (GIS). However, image analysis showed that avalanches released during the event were not detectable in the available SPOT-2/-4 multi-spectral scenes. We see the reason for this in a combination of two factors: (a) a too coarse spatial ground resolution (20 m) of the SPOT-2/-4 multi-spectral imagery; (b) the considerable time-lag (17 and 20 days, respectively) between the event and the acquisition date of the images. Factor a) is seen as the predominant one.

In order to check if avalanche detection efforts would perform better using SPOT panchromatic data, which has 10 m spatial ground resolution, a scene available for the Otta region, approximately 100 km north-east of Tyin (acquired on 15.2.2008), was analyzed. In contrast to the scenes from the Tyin area, there is no ground-truth data on potentially released avalanches available for the Otta area on the date concerned. However, at the time of data ordering, there were generally not many panchromatic winter scenes without extensive cloud cover to choose from.

As for the multi-spectral data, the panchromatic imagery was geo-referenced and integrated into a GIS, in order to detect and map potential avalanches.

Efforts to detect (and eventually map) avalanches on the Otta scene did not yield positive results. First of all, there were probably no avalanches to observe. Furthermore, the illumination of the image was not favorable: north-exposed slopes were mainly in the shadow while south-exposed slopes were “over-illuminated”. This made it nearly impossible to detect any possible avalanche deposits. The expert impression gained through the analysis of this data was, however, that big, fresh avalanches would be detectable in scenes with 10 m spatial ground resolution, when favorable illumination conditions are given.

4.2 Detection of avalanches in VHR optical airborne and satellite data

A total of five QuickBird winter scenes were selected based on the avalanche information visible in the available quick-look information in GoogleEarth and in the reseller's data ordering system. The imagery was collected in the years 2005, 2009 and 2011. One large dataset from the airborne digital push-broom scanner ADS40-SH52 was analyzed in addition.

The work-flow of our analyses consisted in three, partly independent steps: a) manual mapping, b) automated image segmentation, c) automated feature extraction, and d) a combination of b) and c). Steps b, c and d were carried out within ENVI/IDL®, commercial software for processing and analyzing geospatial imagery, with own implemented routines for avalanche segmentation and classification.

In a first step, avalanches were identified and manually mapped in all the available satellite imagery within a GIS environment by an avalanche expert. One part of the resulting avalanche outlines were used as ground-truth data to develop and train the algorithms to automatically detect and map avalanche snow in the training stage. The remaining data was used for verification purposes during the validation stage.

We tested two different segmentation strategies: texture-based segmentation (example result given in Figure 2, cf. Larsen et al., 2010) and segmentation based on directional filters (cf. Larsen et al., 2011).

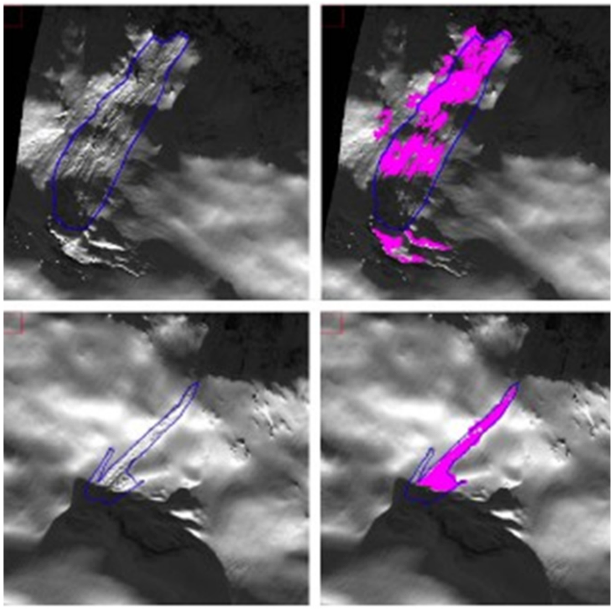

Figure 2: Two avalanches segmented based on texture. Left: Avalanches outlined manually in blue on the panchromatic image. Right: Automatically detected avalanche snow segments overlain in pink (cf. Larsen et al., 2010).

For the directional filter approach a digital elevation model (DEM) was needed as ancillary data. We used a DEM with 15 m spatial ground resolution. This DEM was generated from contour lines of the official 1:50,000 maps of the Norwegian Mapping Authority.

Both segmentation approaches were able to successfully extract avalanche areas. The results indicate that the texture-based approach extracts the outer boundaries of the avalanche better than the directional filter approach, but struggles to separate sparse trees from avalanche snow. The strength of the directional filter approach is that it is able to separate sparse trees from avalanches. The major drawback of this approach is that it tends to confuse shadowed areas with rock.

5. VALIDATION

1.1 Validation with expert data

Validation and quality control of the algorithms and their results using expert data was two-fold: (a) During the initial phase of the algorithm development (training phase) avalanche experts from the avalanche warning group at NGI detected and mapped the avalanches in the analyzed QuickBird images (test images) prior to the automatic detection work. This data was then used in order to train the algorithms; (b) in the validation stage, avalanche outlines were manually mapped by avalanche experts parallel to the automatic detection work. Once the automatic detection was accomplished, the manually mapped avalanche outlines were used to validate the results of the automated routines.

1.2 Validation using end-user data

All data of observed avalanches registered in the database at NPRA for the areas in question and the dates concerned were used to cross-check the mapped avalanches. However, during the observed periods only one of the mapped avalanches could be linked to a registration entry in the NPRA database. For this avalanche both spatial extent and date of occurrence could be confirmed. The low number of concurrence between mapped avalanches (by the algorithm) and recorded avalanches (by NPRA) is partly due to the fact that most avalanches that we analyzed did not reach any roads. Therefore they were not of importance to the road maintenance people who report and record avalanche occurrences to NPRA; consequently, they were not registered. The low concurrence may also be caused by the fact that the location of avalanches in the NPRA database is not registered using coordinates, but locality names. In a few cases it was, therefore, not possible to retrace these localities on the available maps.

6. DISCUSSION

Currently, optical data accessible through the European Space Agency or its Third Party Missions (such as, for example, the here used SPOT-2/-4 data) proves to have insufficient spatial resolution for the purpose of avalanche detection and mapping. This applies especially to the available multi-spectral data, but also, even though to a less pronounced degree, to available panchromatic data. This problem turned out to be inherent for our study which was, therefore, relying heavily on VHR data from commercial resellers, in the present case, namely QuickBird imagery.

Detection and mapping by both visual methods as well as by applying automatic detection algorithms worked well for the used QuickBird data and yielded very promising results. At the time of this report, VHR imagery (≤ 5 m spatial resolution) is, among others, available on a commercial basis from a considerable number of satellites. In addition, new optical satellites become available with increasing frequency. However, this potential future abundance of satellites providing VHR optical imagery should not conceal the fact that image coverage can be quite scarce for certain regions. This is especially true for regions which are (a) either not in the focus of the commercial satellite image providers (typically, regions not prone to large natural hazards or that do not feature large urban areas, are not within the target area of these entities); or (b) areas which are located at high latitudes. The latter is especially true during winter season, due to unfavorable illumination situations at high latitudes during periods with low sun-elevation angle. On the other hand, data-coverage per square kilometer is strongly increasing towards the poles due to the converging nature of the orbits of polar orbiting satellites. This increases the potential coverage of areas of interest at high latitudes.

Operational avalanche detection for inventory and validation purposes will strongly depend on the availability of imagery. Operability could be effectuated by entering on-demand purchase agreements with one (or several) satellite imagery provider(s). The costs involved with the purchase of commercial VHR- imagery should, however, not be underestimated. At present, image availability is, therefore, seen as the main bottleneck for the proposed service (cf. Frauenfelder et al., 2011).

7. CONCLUSIONS AND OUTLOOK

We could show that automatic detection and mapping of occurred avalanches in VHR optical imagery is possible. Our study also showed that such data could be used to add important data to validate avalanche forecasts, something which could lead to significantly improved forecasts.

We think that an operational service for such inventory and verification purposes could be turned into practice once the remaining algorithm challenges have been overcome. It has to be mentioned, however, that image availability and when working with optical imagery, the restriction to clear-sky conditions, pose a significant challenge to putting such a service into operation.

The analyses on the evaluation data showed that the algorithms are able to detect avalanches in images with rather different conditions (such as illumination, snow cover, avalanche freshness, landscape). Performance is best for depositional areas and avalanche paths with little entrained sediment in well illuminated areas without many occurrences of bedrock and/or single trees. The algorithms are able to detect avalanches in both entirely snow-covered slopes and avalanches close to or inside forest.

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