DETECTING BACKCOUNTRY AVALANCHES IN THE TETON RANGE WITH SYNTHETIC APERTURE RADAR (SAR)

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ABSTRACT: Backcountry avalanche activity represents a significant gap in many avalanche centers' databases. To mitigate this we applied remote sensing techniques–specifically Synthetic Aperture Radar (SAR) imaging–to the Teton backcountry to bolster avalanche event data and provide a more comprehensive picture of the region. Using data from the Sentinel 1A and 1B satellites we manually detected a large avalanche in the Tetons that occurred February 2017.

Keywords: synthetic aperture radar, remote sensing, satellites

1. INTRODUCTION

Widespread avalanche activity is one of the most reliable indicators of avalanche danger and is important for reliable forecasting and mitigation. However, piecing together a comprehensive picture of avalanche activity throughout a season is nearly impossible. The location and timing of events in the backcountry is difficult to determine using current field based methods; while data gathered from field expeditions is reliable it tends to be skewed towards easily observable events in good weather. This gap makes carrying out statistically meaningful analyses for the broader region quite difficult. Remote sensing has the potential to fill this gap.

There are many different remote sensing technologies available (optical, LiDAR, infrasonic, etc.) but the one most applicable to widespread backcountry avalanche detection in the Teton range is space-borne Synthetic Aperture Radar (SAR).

2. SAR: TECHNICAL DETAILS AND OVERVIEW

Much like other radar systems, SAR uses the microwave region of the electromagnetic spectrum, making data collection weather and light independent. Sensors measure radar return from a target (this is called *backscatter*) to create high resolution images of the Earth's surface. There are multiple space-borne SAR systems in operation (see Eckerstofer et. al., 2016 for a complete list), but we focus exclusively on the Sentinel 1A and 1B satellites (S1A and S1B) managed by the European space agency. Although the Sentinel 1 constellation does not provide quite as high resolution as some other systems it is currently the only space-borne system providing data free of charge.

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2.1. *Sentinel 1 applicability to the Tetons*

S1A and S1B trace the same path over the Tetons every 12 days (12 day repeat frequency). This means every 12 days we can get images with the same reference geometry. However, due to the high latitude of the Tetons and the wide swath of the Sentinel 1 satellites the revisit frequency is much higher: S1A and S1B pass somewhere over our region every 1-4 days, allowing us to look for avalanches on a fairly frequent basis. Most of the avalanches we will be able to detect will be medium to large sized avalanches; S1A and S1B have a spatial resolution of 5m $\times$ 20m, limiting detection of small avalanches. See Table 1 for technical details.

Table 1: Technical specifications for S1A and S1B over the Bridger-Teton backcountry. Specifications taken from the ESA Sentinel-1 handbook.

Bandwidth	C
Repeat Time	12 days
Revisit Time	1-4 days
Frequency (GHz)	5.4
Swath (m)	250
Polarization	VV and VH
Mode	IW

3. APPLYING SAR TO THE TETONS

The first avalanche debris detection using Sentinel 1 imaging was conducted by Malnes et al. (2015).

Figure 1: Crown and top of the slide path for the Teewinot slide. The slide started at elevation 10037 ft with a start zone angle of 36-40 degrees on the NE slopes.

Figure 2: Runout zone of the Teewinot slide. Debris field forms a distinctive fan-shaped pattern.

The researchers used enriched RGB composite images to display changes in backscatter between a reference image without avalanche activity and one with avalanche activity. This processing allows for the manual detection of avalanche debris. We applied this technique to search for avalanches in the Bridger-Teton backcountry.

3.1. The Teewinot Slide

From February 03 2017 to February 06 2017, the Tetons were hit with a strong, wet northwest storm that deposited a heavy blanket of snow on the region, culminating in valley rain at the end of the week. High southwesterly winds and rapidly warming temperatures contributed to the destabilization of the snowpack and notched the avalanche danger up to extreme. Five days later, on February 11, the northeast slopes of Mt. Teewinot naturally released in a large (R4 D4) avalanche. The Teewinot slide ran full track to the valley and fanned out in the runout zone, creating a distinctive debris field that served as an ideal test case for remote detection (see figures 1-2).

3.2. SAR Image Analysis

The S1A images were downloaded in standard format ground range detected high-resolution (S1-GRDH) and, with the help of researchers from the Norut Research Institute, processed using the GSAR software outlined in Larsen et at., (2005). The GSAR software individually geocoded the images and accounted for layover, shadow areas and foreshortening. The outputs of this processing are radar backscatter images that are further manipulated to form one enriched RGB composite image. RGB composite images display the changes between the two backscatter images in color. The reference image (taken before an avalanche cycle) is displayed in the R and B channels, with the secondary image displayed in the G channel (Malnes et al., 2015). Differences between the two images (i.e. increased backscatter caused by avalanche debris) show up in green.

For optimal detection we selected a reference image from late January prior to the wet storm cycle that kicked off the Teewinot slide. The snowpack in the reference image on January 25 was dry and stable with no significant avalanche activity reported. Twenty-four days later, on February 18, we selected a secondary image that captured the end of the avalanche cycle following the early February storm. Our two satellite images from January 25 and February 18 were combined to make an enriched RGB change detection image in the same manner outlined in Malnes et al., (2015). The RGB image composite was saved as a geotif file so we could manually look for avalanches in a GIS environment.

3.3. Detecting the Teewinot Slide

The distinctive shape of the Teewinot debris field was immediately visible in the enriched RGB change detection image (shown in Figure 3). The fan-like shape of the debris field in the satellite image correlates nicely with the field observations we took (see slide pictures in Figures 1-2).

CONCLUSIONS

The detection of the Teewinot slide, along with the success of researchers at Norut, lead us to conclude implementing remote satellite detection of backcountry avalanches is a feasible option for the Bridger-Teton Avalanche Center. The quick revisit time of the Sentinel 1 satellites combined with comparatively accessible terrain in the Tetons would allow for the Bridger Teton center to reliably validate preliminary results. Such a tool could

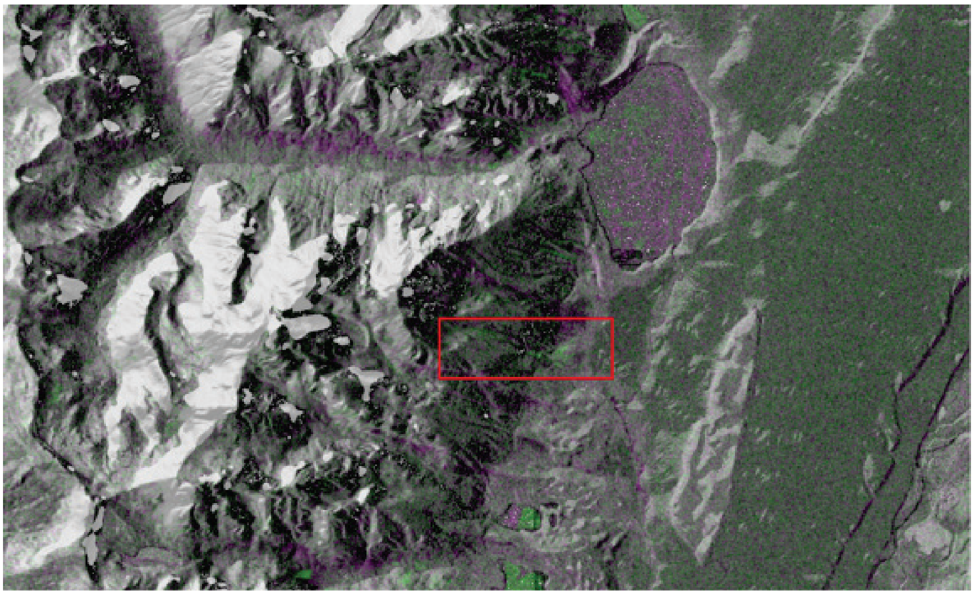

Figure 3: Enriched RGB composite image of Teewinot slide. Slide is boxed in red.

provide invaluable data on avalanche activity.

However, the Sentinel 1 satellites produce large amounts of data, far too much to be analyzed by hand. For remote avalanche detection to ever be used in an operational context there needs to be some sort of automatic avalanche detection algorithm. This is not as easily resolved as manual detection and will be a continued area of interest as we pursue this project.

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REFERENCES

Eckerstorfer, M., Y. Bühler, R. Frauenfelder, and E. Malnes (2016). Remote sensing of snow avalanches: recent advances, potential, and limitations. *Cold Reg. Sci. Technol.*, 121, 126-140.

ESA Sentinel-1 user handbook, (2013). *ESA Standard Document.* GMES-S1OP-EOPG-TN13-0001. 1 September 2013., 80 pp.

Larsen, Y., Engen, G., Lauknes, T. R., Malnes, E., and Høgda, K. A. (2005). A generic differential interferometric SAR processing system, with applications to land subsidence and snow-water equivalent retrieval. *Fringe ATSR Workshop 2005, Frascati, Italy, 28 November-2 December.*

Malnes, E., Eckerstorfer, M., Vickers, H., (2015). First Sentinel-1 detections of avalanche debris. *Cryosphere Discuss.*, 9, 1943-1963.

Vickers, H., M. Eckerstorfer, E. Malnes, Y. Larsen, and H. Hindberg (2016). A method for automated snow avalanche debris detection through use of synthetic aperture radar (SAR) imaging. *Earth and Space Science.*, 3, 446-462.