# MICROWAVE RADAR SYSTEM FOR DETECTING AVALANCHES
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ABTRACT: Key roads in the Western U.S. are often closed by avalanches during the winter. Fortunately, they generally occur in well-defined paths. Knowing when and where an avalanche has occurred and its severity are critical for snowpack management, possible rescue operations, road closures, and control operations. To address these needs, we have developed a commercial Ku-band microwave radar system to monitor avalanche paths to provide warning to avalanche safety personnel, who can warn skiers and motorists, and trigger automatic road closures in critical locations. Mounted in a small enclosure with a line-of-sight view of the slide area, it monitors radar backscatter changes with time that are indicative of a slide. The system includes phased array electronic steering in azimuth and range compression to enable us to monitor multiple paths and identify the location and extent of avalanches. The self-contained system operates autonomously and is available in a variety of configurations. In this presentation we briefly describe the system and present some field test results from the Mt. Superior slide path in Little Cottonwood Canyon (LCC), Utah.

KEYWORDS: Avalanche detection, radar, remote sensing

## I. INTRODUCTION

Snow avalanches that affect roads in the Western U.S. generally occur in well-defined locations but can represent significant hazards to motorists. Early detection of avalanches that can impact the road can enable rapid road closure and the dispatch of emergency personnel. It can also provide avalanche forecasting crews with invaluable information about control work results. Since avalanches can occur at any time, an avalanche sensor needs to operate in all weather conditions day or night. By providing its own illumination and all-weather capability, radar provides an ideal tool for avalanche detection as well as avalanche forecasting. A viable detection system needs to be low cost, easily deployed, and provide an effective system for data distribution to end users.

In this paper we describe a new commercial radar system to address these needs. The self-contained detector system includes a Ku-band radar optimized for avalanche detection and a video camera. Automated electronic messaging can provide real-time information on detection of an avalanche, including size and location. We present experimental results from a field test of the system at the Mt. Superior slide path in Little Cottonwood Canyon, Utah.

## II. RADAR SYSTEM

A summary of some of the key design

TABLE 1
SUMMARY OF AVALANCHE DETECTION RADAR SYSTEM

| |
|---|
| Frequency:    12.5 GHz (Ku-band) |
| Linear frequency modulated continuous wave (LFM-CW) |
| Antenna beamwidth 40 deg (steerable) |
| PRF:  1 kHz |
| Transmit power: 3 W |
| Range resolution: 1 m |
| Detection range: 1 km slant range swath starting 100 m to 3 km from radar |

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Fig. 1. Location of the Mt. Superior site in Utah.



Fig. 2. Mt. Superior site showing the location of roads, buildings, and the radar viewing area. The radar is sited at the lower corner of the green coverage area.

specifications for the radar is given in Tab. 1. The new commercial radar operates at Ku-band with a wavelength of approximately 2 cm. This wavelength is well suited for observation of snow and ice conditions in avalanche zones. The low-power transmitted system uses continuous linear frequency modulation (LFM-CW) to provide better than 1 m range resolution over a 1 km wide swath. To providing siting flexibility, the swath location can be set anywhere from 100 m to 3 km from the radar. LFM-CW operation minimizes transmit power for operation at the desired signal-to-noise ratio (SNR). The coherent radar employs offset homodyne mixing and digital Fourier processing of the received signal to generate backscatter versus slant range data (Zaugg et al, 2008). Multiple pulses are averaged to increase the operating SNR.

The self-contained bi-static radar is approximately 20 cm by 20 cm by 10 cm including antennas, and is designed to be mounted on a pole or existing structure outside of the slide path. The radar employs pulse-to-pulse change detection to detect motion within the swath area. The antenna system includes electronic phase steering to cover an area of up to $\pm 60°$ around the antenna mechanical boresite to support a large coverage zone. The azimuth and range resolution combine to enable localization of movement to within 1 m in range and 2 m in azimuth.

The radar system generates a rapid sequence of range/azimuth images where the pixel value is the backscatter of movement within the pixel. Software can mask out areas not of interest to enable detection of movement corresponding to a slide. In field tests we find that the system can easily detect and track moving skiers, dogs, and deer, as well as vehicles. This incidental capability is particularly useful in helping assure that the area is clear of people and vehicles before initiating an avalanche in active clearing operations.

## III. FIELD EXPERIMENT SITE

A field evaluation of the prototype of the commercial unit was conducted on Mt. Superior in Little Cottonwood Canyon, Utah in



Fig. 3. Winter view of Mt. Superior from radar site. Note the road running at the base of mountain in the slide run-out zone.
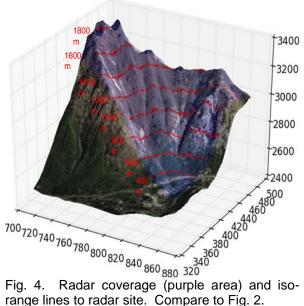
Fig. 4. Radar coverage (purple area) and iso-range lines to radar site. Compare to Fig. 2.

the winter of 2015-2016. LCC is located in the central part of the Wasatch Mountains in Utah (Fig. 1) (Nalli, 2016). SR 210 runs the length of the canyon from the Salt Lake Valley to the town of Alta (Figs. 2 and 3). Along its upper 14 km, lie 64 avalanche paths, the Snowbird and Alta ski areas, and numerous public and private buildings. Mt. Superior sits between the Snowbird Village and Alta from 11,040' at the summit to 8,200' at the runout in LCC Creek. It is an ideal location for

testing because it receives 500" of annual snowfall on average and has many human and naturally triggered avalanches each year.

In partnership with the Snowbird Ski and Summer Resort, a convenient site below a Powderbird helipad was selected. The site offers a good, unobstructed view of the avalanche path, power, and an internet connection to enable control and monitoring of the system, as well as dissemination of avalanche detection. For the purposes of the experiment, raw radar data was saved to disk for detailed analysis, and continuous video of the slope was collected. The latter proved invaluable for validation of detected avalanches during day-light hours and good weather.

The site and area covered by the radar coverage area are illustrated in Fig. 4. Note that radar was sited across the canyon from the toe of the slide area looking up the slope over the road, (Figs. 2 and 3). The road is frequently closed due to avalanche danger, and artillery control operations are regularly conducted to reduce the possibility of a natural avalanche impacting the open road and endangering motorists. A 3D map of the observation area showing lines of constant range from the radar is shown in Fig. 4.

In addition to general monitoring of the slide area by radar, a number of controlled experiments were conducted, including
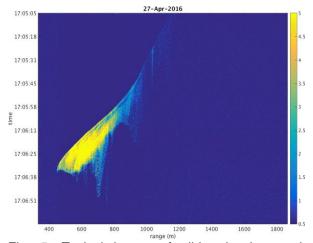


Fig. 5. Typical image of slide showing total backscatter from moving objects versus time. The slide begins at top at a range of 1.1 km. The slide ends at approximately 450 m from the radar. At a given range, the vertical extent gives the time in motion of the slide, including settling time. Time runs from top to bottom.
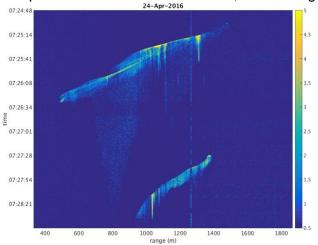


Fig. 6. Multiple slides triggered by explosives. The first slide triggers a secondary slide which has a long settling time at around 800 m, indicating snow compaction. The lower slide is triggered by a separate explosive charge.
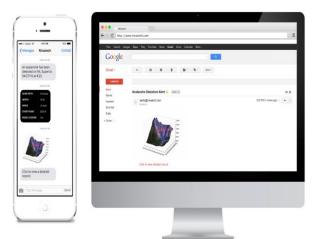
Fig. 7. Example of an avalanche notification sent via text or email. This can be updated in real time during the avalanche depending on user-set thresholds on slide size and run-out distance.

artillery initiated avalanches and a group of skiers hiking to the top and skiing down the slope. In addition to artificially triggered avalanches, observers reported a number of natural avalanches as well.

## IV. FIELD EXPERIMENT RESULTS

The system successfully detected natural and human-triggered avalanches in the test area. When usable (i.e., during clear weather and in day-light hours), video was used to confirm every detected avalanche. One false-alarm detection was observed due to a small group of deer moving through the area. The detection algorithm was adjusted to avoid this is in the future. No missed detections were observed in the examination of video collected during radar operation. One advantage of Ku-band operation is that we encountered no interference.

Two examples are discussed here. Figure 5 illustrates an example of an avalanche seen in the radar data. The plot shows distance from the radar along the horizontal axis and time (running from the top toward the bottom) on the vertical axis. The pixel value shows the change in backscatter in arbitrary log units from pulse cycle to pulse cycle. Low values indicate no motion, while movement is revealed as lighter colors, with lighter colors revealing the amount of movement and total

area affected at a given range. The motion is averaged over the azimuth coverage in these plots.

Note that the slide begins at the top at a range of about 1100 m, and propagates toward the radar as a function of time. The leading edge of the avalanche provides a sharp boundary between no-motion and motion, and aids in event detection. At a given range, the vertical band is the result of continuing movement and settling. This natural D2 avalanche was the largest slide observed but stopped well short of the road. Receiving real time notification of events like these are invaluable pieces of information to the avalanche forecaster.

Example radar observations of human triggered slides are shown in Fig. 6. The first slide, which begins at the top at a range of nearly 1500 m, initiates a secondary slide that propagates further downhill, ending at about 500 m. Note that the time for the surface to come to rest is very long at 800 m. A minute later another slide begins at a range of about 1400 m and ends at 900 m. We note that the bright, narrow vertical bands in these slides are associated with snow pouring over a cliff channel as confirmed with video. (The vertical stripe strip in the image is a temporary noise artifact from the radar power supply.)

By mapping the data onto 3D maps of the slope, the slide location and extent in azimuth and range can be determined, and included in alerts and forecast information.
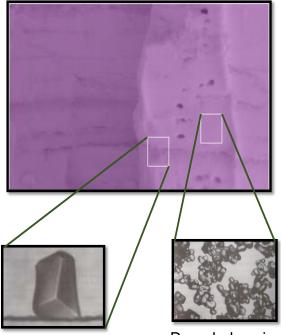
## V. SYSTEM OPERATION

The radar operates continually, collecting backscatter versus range data. The difference between consecutive pulses is computed and averaged to detect motion.

A running Radon transform can rapidly detect the initiation and propagation of the avalanche down slope. In this area, detection is typically available within seconds of the initiation of the avalanche. With the simultaneous location information, coupled with historical data, forecasts of the possible runout distance can be made. A rapid alert during the avalanche can be used by operational personnel to possibly close the

road and/or dispatch emergency personnel. The alert can be updated during and after the avalanche run as needed (Fig. 7). To most efficiently accomplish this, a cloud-based alert system is used to archive radar and video data, set detection thresholds, maintain contact lists, and disseminate alerts to users. The cloud-based server provides a simple, uniform interface to the overall system, and allows users to go back and examine radar and video data as desired.

## VI. CONCLUSION

A new avalanche detection radar system has been developed and demonstrated in the field. Designed for ease of use, the system is small, easy to use, simple to deploy and setup, and requires little maintenance. It includes a cloud-based service to provide real-time alerts via email or text messaging when avalanches are detected.

The system is currently commercially



Faceted grain     Rounded grains

Fig. 8. Infrared image of snow pit stratigraphy with insets illustrating the grain size in each layer. Larger grain sizes produce larger radar backscatter, enabling differentiation of the grain size in each layer. The observed time evolution of the grain size can be useful in avalanche forecasting.

available from Niivatech. In cooperation with the Utah Department of Transportation, systems will be deployed in several locations in Utah this winter to assist in avalanche operations, including forecast, detection and hazard mitigation. While designed for snow avalanche detection, the system can also be used for landslide detection (McHugh et al., 2004) and people movement.

Enhanced stratigraphy monitoring capability is possible by combining the basic radar with a mechanical scanning system to create a high-resolution ground-based remote stand-off synthetic aperture radar system that can provide much finer spatial resolution and extract 3-D information. This permits direct measurement of the snowpack accumulation. Monitoring the temporal evolution the backscatter in each 3-D snowpack voxel can provide macro-scale layering information to aid in avalanche forecasting (Long and Preston, 2015), (Fig. 8). An additional system with this capability will become commercially available in the near future.

## REFERENCES

Long, D.G., and S.J. Preston, 2015: Method, Apparatus, and System to Remotely Acquire Information from Volumes in a Snowpack, U.S. Patent 8,581,772.

McHugh, E.L., D.G. Long, and C. Sabine, 2004: Applications of ground-based radar to mine slope monitoring, *ASPRS Annual Conference Proceedings*, 12 p., Denver, Colorado.

Nalli, B., 2016: Modernizing North America's oldest avalanche program in Little Cottonwood Canyon, Utah. International Snow Science Workshop.

Zaugg, E.C., and D.G. Long, 2008: Theory and Application of Motion Compensation for LFM-CW SAR, *IEEE Transactions on*