RESEARCH

UDOT CONNECTING COMMUNITIES

Utah Department of Transportation - Research Division
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**Report No. UT-09.01**

# INFRASOUND AVALANCHE MONITORING SYSTEM RESEARCH EVALUATION

**Prepared For:**

Utah Department of Transportation
Research Division

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16. Abstract

Little Cottonwood Canyon Road (SR-210) has one of the highest risks for avalanche activity for almost any road in North America. Until recently, UDOT staff members have generally relied on visual cues to know whether avalanche control operations have successfully triggered slides (the same holds true for naturally occurring slides). However, in poor lighting or blizzard/whiteout conditions, staff cannot visually monitor whether control operations were successful, or if there is still a risk of avalanche. In 2006, UDOT installed an Infrasonic Avalanche Detection system to monitor three locations in Little Cottonwood Canyon. The Infrasonic provides remote sensing of avalanche activity, so that in poor visibility conditions UDOT staff members are aware of whether an avalanche risk remains or not. The purpose of this research is to evaluate the performance and value of the Infrasonic and determine whether it increases the reliability of avalanche control operations, thereby enhancing public safety.

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# EXECUTIVE SUMMARY

Little Cottonwood Canyon Road, or SR-210, connects the Salt Lake Valley with the Town of Alta, Alta Ski Lifts, and Snowbird Ski Resort at the top of Little Cottonwood Canyon (see Figure 2 for a map of the study area). The road is the only method of access for the communities, resorts, trailheads, and private properties along the canyon's length. SR-210 is threatened by 35 major avalanche paths; all but three of these paths originate on the southerly facing slopes on the north side of the canyon. The White Pine, White Pine Chutes, and Little Pine avalanche paths are some of the most active paths in Little Cottonwood Canyon. The steepness and confined nature of these paths allows even small to medium sized avalanches to reach the road. These paths frequently respond first in natural avalanche cycles triggered by heavy precipitation.

**Figure 1: SR-210 near the White Pine Chutes Avalanche Paths**

Currently, avalanche control is accomplished through road closure and artillery control, occasionally supplemented by helicopter control. The Utah Department of Transportation (UDOT) has a seasonal staff of four full-time avalanche forecasters stationed in the canyon, who coordinate closely with snow safety departments at the local ski areas. The Little Cottonwood Canyon forecasters have some of the most technologically advanced equipment available, but they still face problems in the canyons. For instance, in inclement weather or low visibility, they cannot determine visually whether avalanche activity is occurring naturally or whether control efforts have been successful. Furthermore, visual confirmation can mean placing UDOT staff in danger of avalanche activity. Unlike avalanche control operators at the ski resorts, the Little Cottonwood Canyon forecasters cannot use ski lifts to access the avalanche starting zones and determine if control efforts have been successful. To combat this problem, UDOT installed an Infrasonic Avalanche Detection system in 2006 to monitor three locations in Little Cottonwood Canyon: White Pine, White Pine Chutes, and Little Pine. The Infrasonic provides remote sensing of avalanche activity to allow Little Cottonwood Canyon forecasters to monitor avalanche risks when visibility is poor. Prior to installation, the Little Cottonwood Canyon forecasters hoped that the Infrasonic would provide early warning of natural avalanche cycles and confirm avalanche control efforts.

The purpose of this research evaluation is to address these questions:

1. Does the Infrasonic provide reliable early warning of natural avalanche cycles and confirm control operations?
2. Does the Infrasonic reduce costs for UDOT?
3. How could the Infrasonic system be improved?
4. Would an expanded Infrasonic system benefit UDOT (or other state DOTs)?

Several methods were used to ascertain this information. Interviews of key staff members were conducted. These included all Little Cottonwood Canyon forecasters: Liam FitzGerald, Paul Garske, Chris Covington, and Adam Naisbitt. All four have experience using the Infrasonic regularly. In addition, the research team obtained data outputs from the Infrasonic system. This included screen captures of various user interface components for two case study examples: a natural avalanche cycle and controlled avalanche operations. Notes from the forecasters' logs from those dates were also obtained to compile a narrative of how the Infrasonic guides human decision-making. Comparable remote monitoring technologies were reviewed, including other infrasound monitoring systems, geophones, ground-based radar, and track sensors.

The analysis showed that the Infrasonic did provide early warning of natural avalanche cycles. It also showed that the Infrasonic confirms the success (or failure) of avalanche control operations. In the past, unless avalanche control operations triggered slides that reached the road, the Little Cottonwood Canyon forecasters generally could not confirm whether control efforts were successful, particularly if visibility was poor. The Infrasonic allows the forecasters to know, in real time, whether the ammunition hit the target; whether the ammunition detonated; and whether the detonation triggered an avalanche.

The Infrasonic likely reduces costs, though this may not be quantifiable yet. First, the Infrasonic improves public safety by providing better information for road closure decisions. Second, the Infrasonic improves safety for UDOT avalanche control staff. In the past, if the avalanche forecasting team was not able to verify whether control operations in White Pine or Little Pine had been successful, their choices were either to assume the risk or send someone out to verify efforts in the field. Both of these benefits can be considered in terms of the cost of human lives, whether they represent members of the public or UDOT staff: either way, improved safety reduces these intangible costs. Third, the Infrasonic can potentially reduce the duration of road closures, which represents an economic benefit to the ski resorts in Little Cottonwood Canyon. Fourth, the improved efficiency of avalanche control operations in Little Cottonwood Canyon can reduce staffing costs. Shorter road closures requires less time from both UDOT staff and the Salt Lake County Sheriff, which assists in canyon sweeping efforts and controlling traffic at the base of the canyon.

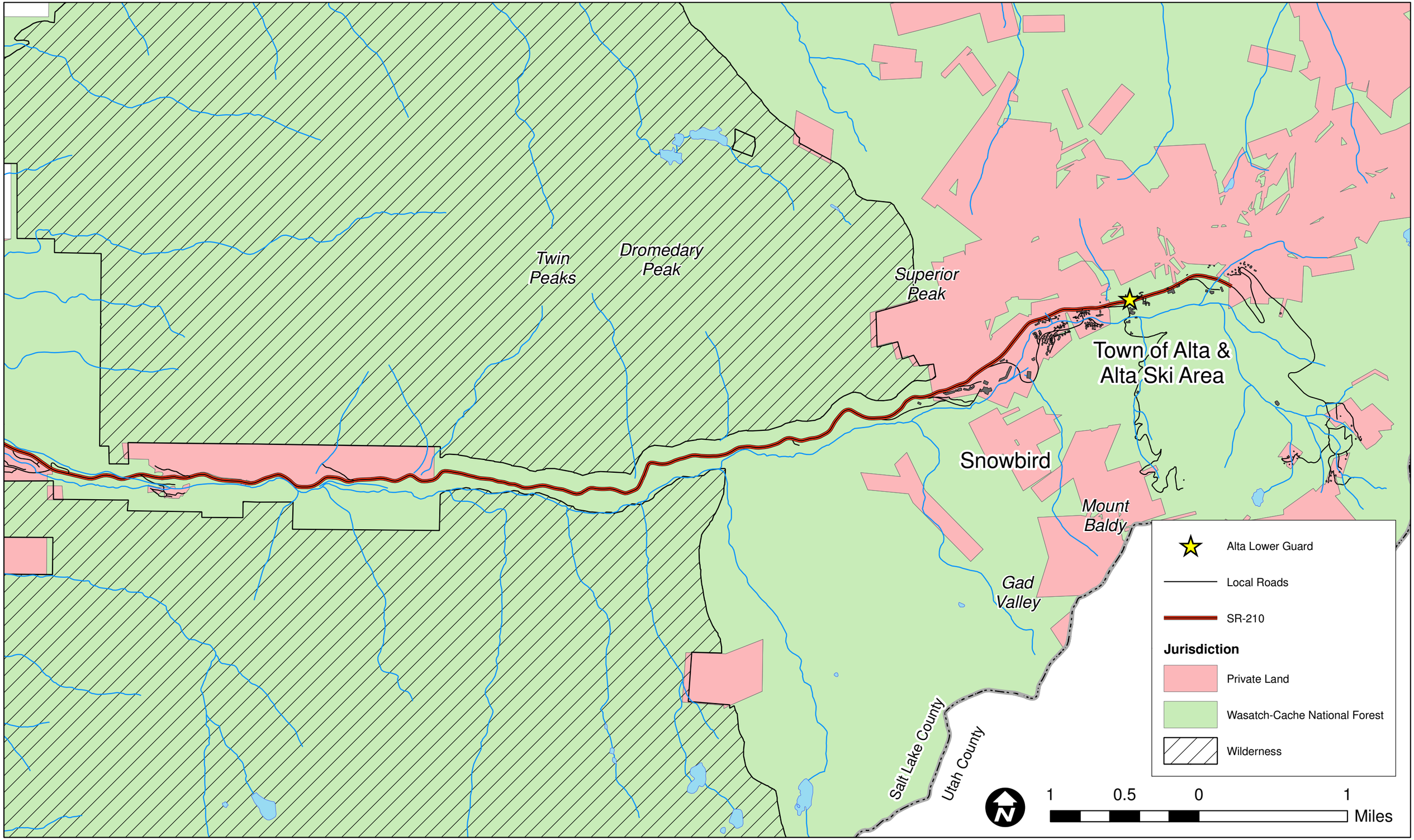
UDOT staff unanimously agreed that the system's usefulness justified its expansion. In Little Cottonwood Canyon, several locations were identified for system expansion: above the Town of Alta, Snowbird Village, between Little Pine and Snowbird Entry 4, or Slide Canyon in Provo Canyon. However, there are some limitations to the Infrasonic. These include UDOT's limited legal ability to manipulate the software codes; communication glitches; and a limited potential for transferability of the system to new locations and new user groups.

# 1.0 INTRODUCTION

## 1.1 Background

Little Cottonwood Canyon Road, or SR-210, connects the Salt Lake Valley with the Town of Alta, Alta Ski Lifts, and Snowbird Ski Resort at the top of Little Cottonwood Canyon (see Figure 2 for a map of the study area). The road is the only method of access for the communities, resorts, trailheads, and private properties along the canyon's length. SR-210 is threatened by 35 major avalanche paths; all but three of these paths originate on the southerly facing slopes on the north side of the canyon. The White Pine, White Pine Chutes, and Little Pine avalanche paths are some of the most active paths in Little Cottonwood Canyon. The steepness and confined nature of these paths allows even small to medium sized avalanches to reach the road.

Currently, avalanche control is addressed by road closure and artillery control, occasionally supplemented by helicopter control. The Infrasonic infrasound monitoring system was installed in the White Pine/Little Pine area in 2006 to assist with avalanche control efforts in this area. The Infrasonic detects infrasound signals emitted by avalanche activity and transmits it to a computer at the Alta Lower Guard station, where the signals are viewed by the Little Cottonwood Canyon avalanche forecasters. The Infrasonic allows UDOT forecasters in Little Cottonwood Canyon to monitor avalanche activity in poor visibility conditions so that they are aware of whether an avalanche risk remains.




UDOT GOING THE EXTRA MILE

**Figure 2: Study Area**

### 1.2 Scope of the research

The purpose of this research evaluation is to address the four following questions:

1. Does the Infrasonic provide early warning of natural avalanche cycles, and confirm avalanche control operations?
2. Does the Infrasonic reduce costs for UDOT?
3. How could the Infrasonic be improved?
4. Would an expanded Infrasonic system benefit UDOT or other state DOTs?

The overall goal for this evaluation is to determine whether the Infrasonic met stated expectations and whether it would be worthwhile for UDOT to expand the Infrasonic elsewhere, either in additional locations in Little Cottonwood Canyon or in other locations throughout the state. To address these questions, the research team interviewed several individuals, analyzed system output from the Infrasonic, and researched comparable systems.

### 1.3 Contents of this publication

This publication summarizes Little Cottonwood Canyon avalanche history and conditions, and describes in detail the Infrasonic avalanche monitoring system, including its hardware and software. This publication evaluates the effectiveness of the Infrasonic through user interviews and analysis of data output from the user interface. It identifies advantages and limitations of the current Infrasonic and recommends future applications.

## 2.0 RESEARCH METHODS

### 2.1 History of avalanche control in Little Cottonwood Canyon

Little Cottonwood Canyon Road, or SR-210, connects the Salt Lake Valley with the Town of Alta, Alta Ski Lifts, and Snowbird Ski Resort at the top of Little Cottonwood Canyon (see Figure 2 for a map of the study area). SR-210 is threatened by 35 major avalanche paths; all but three of these paths originate on the southerly facing slopes on the north side of the canyon. See Figures 4 and 5 for an illustration of natural and controlled avalanche activity in Little Cottonwood Canyon, from 1973 through 2008. As seen in the figures, the White Pine, White Pine Chutes, and Little Pine avalanche paths are some of the most active paths in Little Cottonwood Canyon. The steepness and confined nature of these paths allows even small to medium sized avalanches to reach the road. These paths frequently respond first in a natural avalanche cycle caused by heavy precipitation, wind conditions, snowpack layering characteristics, and temperature patterns. Currently, avalanche control is addressed by road closure and artillery control,

occasionally supplemented by helicopter control. UDOT has a seasonal staff of four full time avalanche forecasters stationed in the canyon; these forecasters work closely with the snow safety departments at the local ski areas to coordinate on highway avalanche decisions.

In the years following World War II, significant advancements occurred in avalanche control and management through the introduction of military artillery as a tool to release avalanches artificially. As Utah's ski industry grew, the requirements of the avalanche safety program grew also, and by the mid-1960s a well-established forecasting, control, and rescue operation had greatly improved the capabilities of addressing multi-day storms, large avalanches, and ever increasing numbers of road users on SR-210. When Snowbird Ski Area opened in 1971, the Forest Service controlled avalanche paths using an artillery piece in upper Gad Valley, allowing avalanche control work to be carried out in this section of the canyon during storms and the road to be opened more rapidly. Avalanche science progressed over the next decades with the addition of more effective weapons, improvements in weather and snowpack monitoring capabilities, and the participation of several well-trained individuals who were willing to spend their careers focusing on the avalanche problems in Little Cottonwood Canyon.

UDOT is responsible for avalanche safety on SR-210. Numerous remote weather stations feed data to the UDOT Highway Avalanche Forecast Office (generally referred to as Lower Guard Station) on a continual basis from late fall to late spring. UDOT uses three military weapons for highway avalanche control work in Little Cottonwood Canyon: two 105 mm Recoilless Rifles, and one 105 mm Howitzer. These weapons are located on U.S. Forest Service administered lands within the permitted areas of the Alta and Snowbird ski areas. They are staffed by Alta and Snowbird ski patrollers who work under UDOT's direction while carrying out control work above SR-210. UDOT contracts with a local helicopter ski operation to conduct control work as needed to supplement the artillery. A trailer-mounted Avalauncher is sometimes used to control certain avalanche paths affecting the road when the more extensive work by artillery is not necessary. An avalanche track sensor has been installed in one of the more frequently running avalanche paths affecting the road. This device physically detects avalanche debris and provides immediate notification of avalanche activity in that area. While it is suitable in several locations, it is not permissible within wilderness boundaries because it is considered a permanent installation.

**Figure 3: Avalanche Control Operators**

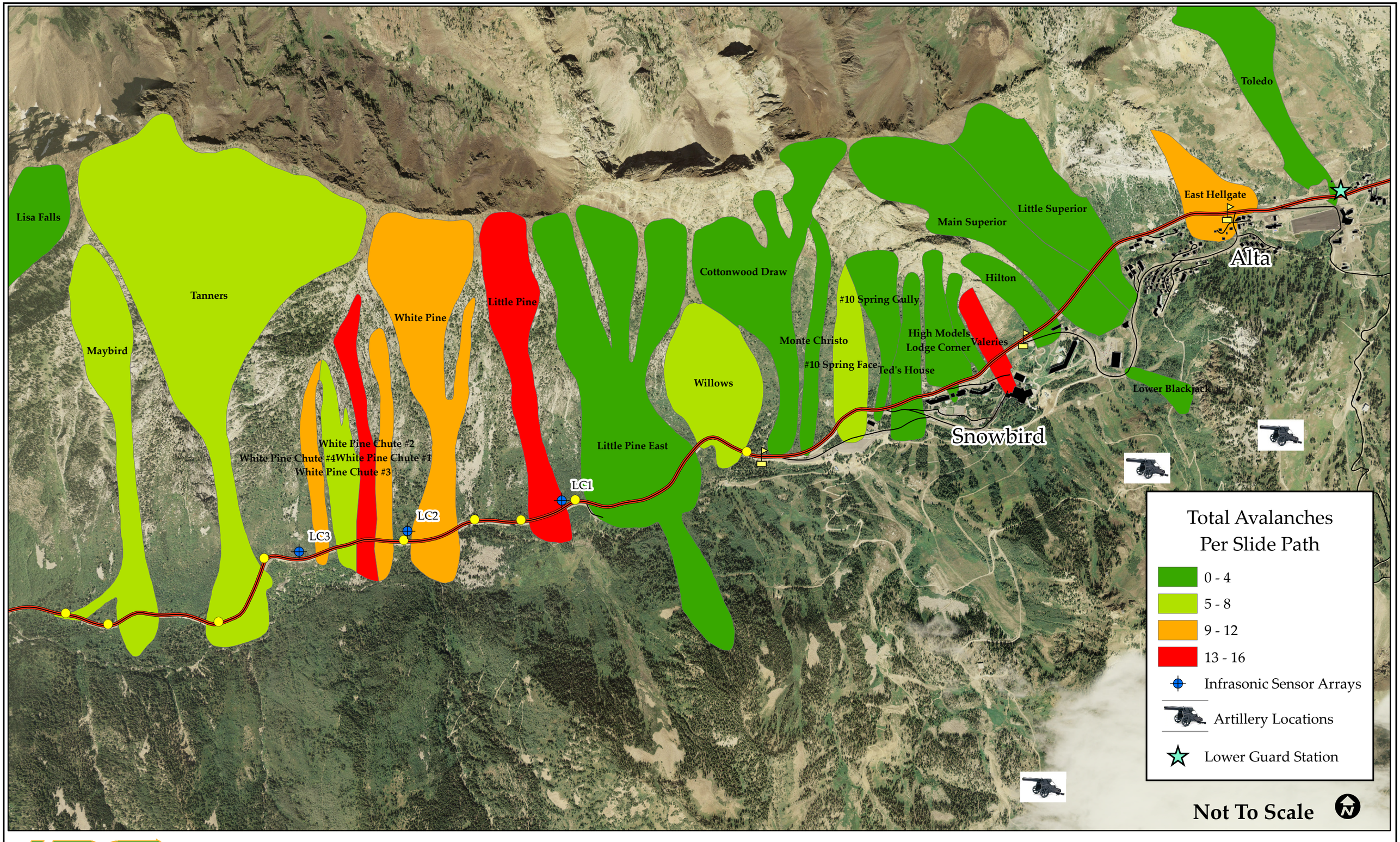



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**Figure 4: Natural Avalanches Reaching the Road: 1973 - 2008**

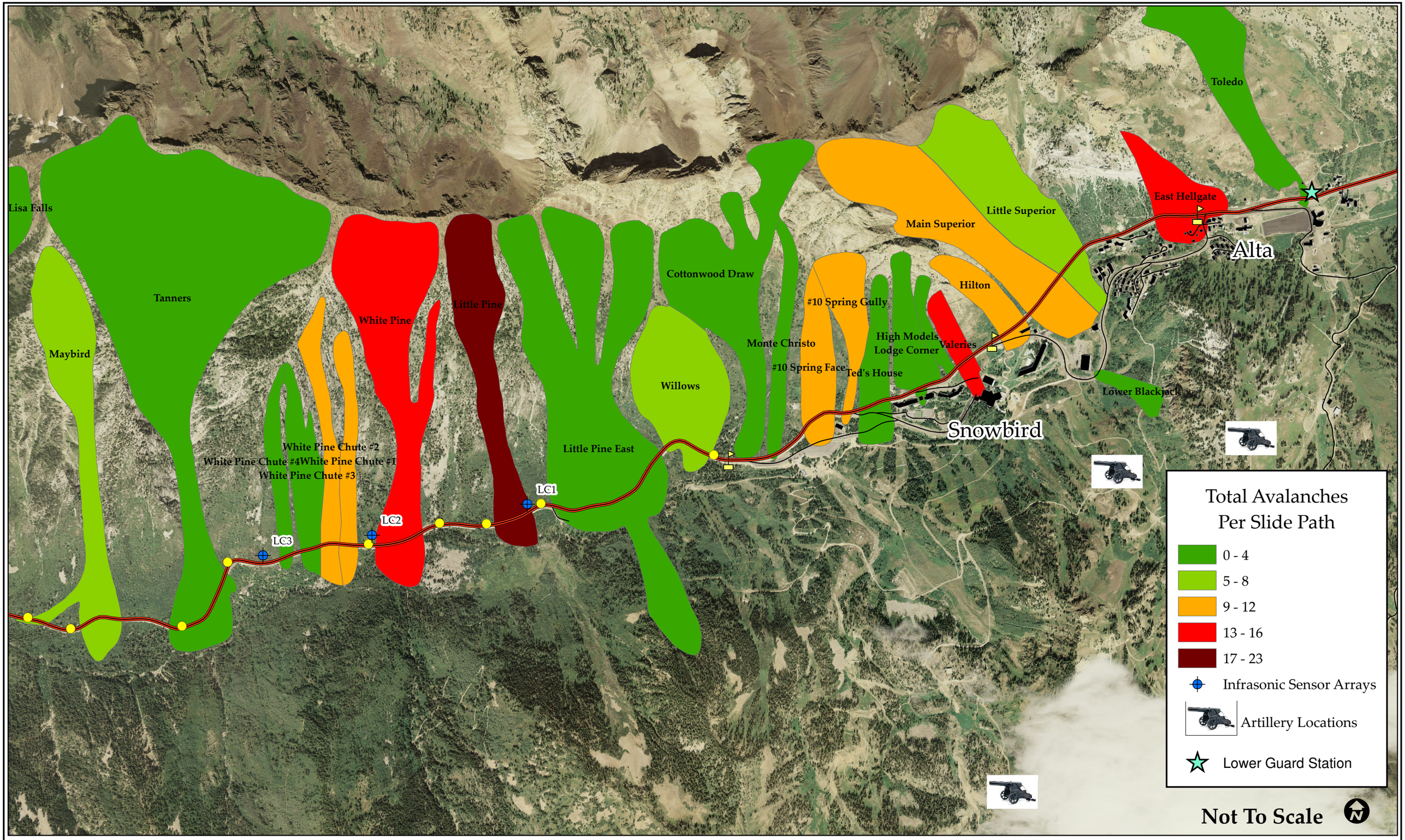


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**Figure 5: Controlled Avalanches Reaching the Road: 1973 - 2008**

It should be recognized that the organizations and individuals charged with keeping SR-210 safe for travel during the winter months have done a remarkable job for nearly six decades, under extremely challenging conditions. Much of the success can be attributed to hard work and a sound program, but in light of the many close calls that have occurred, there has been a good measure of luck involved as well. A continued reliance solely on forecasting, closure and control, is likely to lead to more frequent and sometimes unnecessary road closures and, more importantly, the continued possibility of an unanticipated natural avalanche occurring while the road is open, which could result in injury or death. In addition, the current program relies almost completely on the use of military artillery to control the avalanche paths above SR-210, Snowbird Village, and the Town of Alta. Numerous safety, security, and environmental concerns surround the use of military artillery in Little Cottonwood Canyon, and the artillery program could be terminated at any time. Because of these concerns, an investigation into alternative technologies to the present avalanche safety program is a timely and worthwhile exercise.

The Infrasonic Avalanche Detection system is one alternative that UDOT has chosen to pursue to provide better information in roadway decisions. In 2006, UDOT installed the Infrasonic to monitor three locations in Little Cottonwood Canyon: White Pine, White Pine Chutes, and Little Pine. The Infrasonic provides remote sensing of avalanche activity, so that in poor visibility conditions UDOT staff members are aware of whether an avalanche risk remains or not. The Infrasonic is developed and manufactured by InterMountain Labs (IML), a geologic technology firm based in Sheridan, Wyoming. Beginning in 2002, IML began developing an infrasound monitoring system for avalanche detection (the Infrasonic), using research and development grants from the National Oceanic and Atmospheric Association (NOAA), the National Science Foundation (NSF), and the Wyoming Department of Transportation (WYDOT). The first Infrasonic was installed at Teton Pass, Wyoming, for the 2002 – 2003 snow seasons.

## 2.2 Research Methodology

Several methods were used to determine the effectiveness of the Infrasonic and its potential for expansion. First, interviews of key staff members were conducted. These included all four UDOT Little Cottonwood Canyon forecasters: Liam FitzGerald, Paul Garske, Chris Covington, and Adam Naisbitt. All four individuals have experience working with the Infrasonic system on a daily basis. Avalanche control in Little Cottonwood Canyon requires detailed knowledge of the canyon and its microclimate, topography, and historical avalanche cycles. UDOT cultivates a long-term forecasting team in this canyon to retain and pass on institutional knowledge of local avalanche history and conditions. Some team members have decades of experience in this canyon, while others represent a new generation; however, the newer generation has more highly developed technical aptitude and computer skills, and nicely complements the more experienced team members.

Other interviewees included Bill Nalli, Jamie Yount, and Ernie Scott. Bill Nalli is the UDOT avalanche forecaster for Provo Canyon. The Infrasonic's original Utah location was Provo Canyon. However, the Provo Canyon test location did not provide suitably frequent avalanche activity to test and refine the Infrasonic. Bill Nalli was familiar with the Infrasonic, and had seen it several times in operation – both in Provo Canyon and Little Cottonwood Canyon. The research team also interviewed Jamie Yount with the Wyoming Department of Transportation (WYDOT). The first installation of the Infrasonic system was in Teton Pass between Victor, Idaho and Wilson, Wyoming (near Jackson Hole). WYDOT worked with Ernie Scott and IML to install experimental infrasound detection monitors in Teton Pass, beginning in the winter of 2002 – 2003. An IML representative was also interviewed in order to get a complete picture of the Infrasonic and its development.

In addition, data outputs from the Infrasonic were obtained. These included Infrasonic screen captures of various user interface components for two case study dates: an example of a natural avalanche cycle (January 9, 2008) and controlled avalanche operations (January 21, 2008). Section 4 of this document provides screen captures from the Infrasonic that demonstrate the information viewed by forecasters on the computer monitor, and Section 4 also explains the data shown and its significance. Notes from the forecasters' daily written logs from those dates were also used to compile a narrative of the Infrasonic's relationship to human decision-making processes.

Comparable remote monitoring systems were also reviewed. While monitoring of avalanches is a relatively recent application of infrasound technology, there is one other example of infrasound avalanche monitoring in place (the Arfang, a system developed in Switzerland). Other technologies briefly discussed include geophones, ground-based radar, and track sensors. These technologies are generally evaluated in terms of their applicability in Little Cottonwood Canyon avalanche paths.

# 3.0 DATA COLLECTION

Data collected includes:

- Information on comparable infrasound or remote sensing avalanche detection devices
- Field research on the operations and processing analysis of the Infrasonic
- Data outputs from the Infrasonic, provided by the Little Cottonwood Canyon forecasters
- Interviews with stakeholders involved in the daily operations of the Infrasonic, as well as developers of the Infrasonic and avalanche forecasters from WYDOT

The research team developed an interview template for use in the stakeholder interviews. Interviews were conducted as shown in Table 1, and interview summaries are available as Appendix A to this report.

**Table 1: Interviews Conducted**

| Name | Position | Interview Date |
|---|---|---|
| Bill Nalli | UDOT Avalanche Forecasting, Provo Canyon | October 22, 2008 |
| Liam FitzGerald | UDOT Avalanche Forecasting, Little Cottonwood Canyon | October 23, 2008 |
| Jamie Yount | WYDOT Avalanche Forecasting | October 27, 2008 |
| Chris Covington | UDOT Avalanche Forecasting, Little Cottonwood Canyon | October 28, 2008 |
| Paul Garske | UDOT Avalanche Forecasting, Little Cottonwood Canyon | October 28, 2008 |
| Ernie Scott | Intermountain Labs, Inc. | October 29, 2008 |
| Adam Naisbitt | UDOT Avalanche Forecasting, Little Cottonwood Canyon | October 30, 2008 |
| | | |

# 4.0 DATA EVALUATION/ANALYSIS

## 4.1 Description of the Infrasonic

The Infrasonic provides remote sensing of avalanche activity, so that in poor visibility conditions the Little Cottonwood Canyon forecasters know if avalanches have occurred. Avalanche activity produces infrasound, which is a frequency too low for the human ear. It can be detected by infrasound monitors, which are placed near the avalanche paths. The infrasound sensors sit on wooden pallets, and are attached to a series of cables extending outward from each sensor. The

Little Cottonwood Canyon infrasound system is composed of three separate arrays: Little Cottonwood 1 (LC1), Little Cottonwood 2 (LC2), and Little Cottonwood 3 (LC3). Each sensor array has six sensors. The sensors are powered by solar panels and transmit data via cables to a central datalogger at the array, which in turn transmits the data to Alta's Lower Guard station via wireless radio link. At Lower Guard, a central processing unit (CPU) compiles the data which is then presented through a user interface. The Infrasonic operates in near real-time, providing information in 90-second intervals on a continual basis.

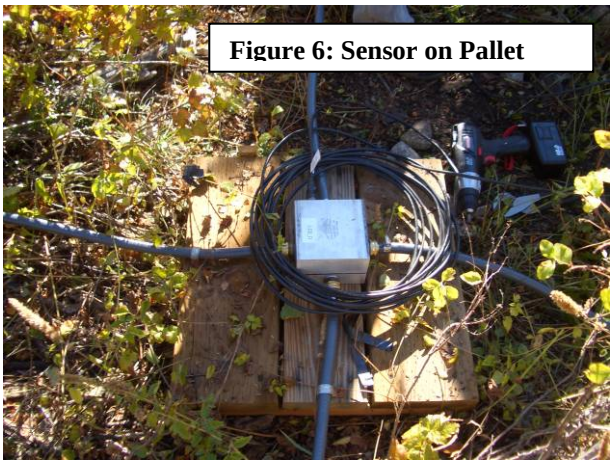


**Figure 6: Sensor on Pallet**

The CPU at Lower Guard processes the data from the arrays to determine which of the transmitted signals represent avalanche activity. Upon receiving data from LC1, LC2, and LC3, a signal analysis is performed on the data to screen for avalanches. A signal analysis will first determine whether any infrasound signal events have been detected. If infrasound signal events were detected, the CPU will classify each detected signal event as either an "identified" avalanche event or as a "discriminated" non-avalanche, or interference, event. The CPU also evaluates the x and y coordinates of the detected infrasound signals, and determines the direction of movement of the signals. Detected infrasound signals exhibiting movement consistent with a targeted avalanche event are designated as avalanches, while detected signal events that appear stationary are designated as interference. The CPU classifies each event into either an "identified" bin or a "discriminated" bin, which are then represented to the user as red or yellow command buttons, respectively. The user can then inspect the signal events assigned to either of the two bins by clicking on the appropriate command button.

**Figure 7: Sensor Array Datalogger**

The command button also displays the statistics used to classify the infrasound signal event, and a geographic image showing the location of the detected infrasound signal source. Several sets of criteria are used to define the parameters for classified avalanche activity. The detected

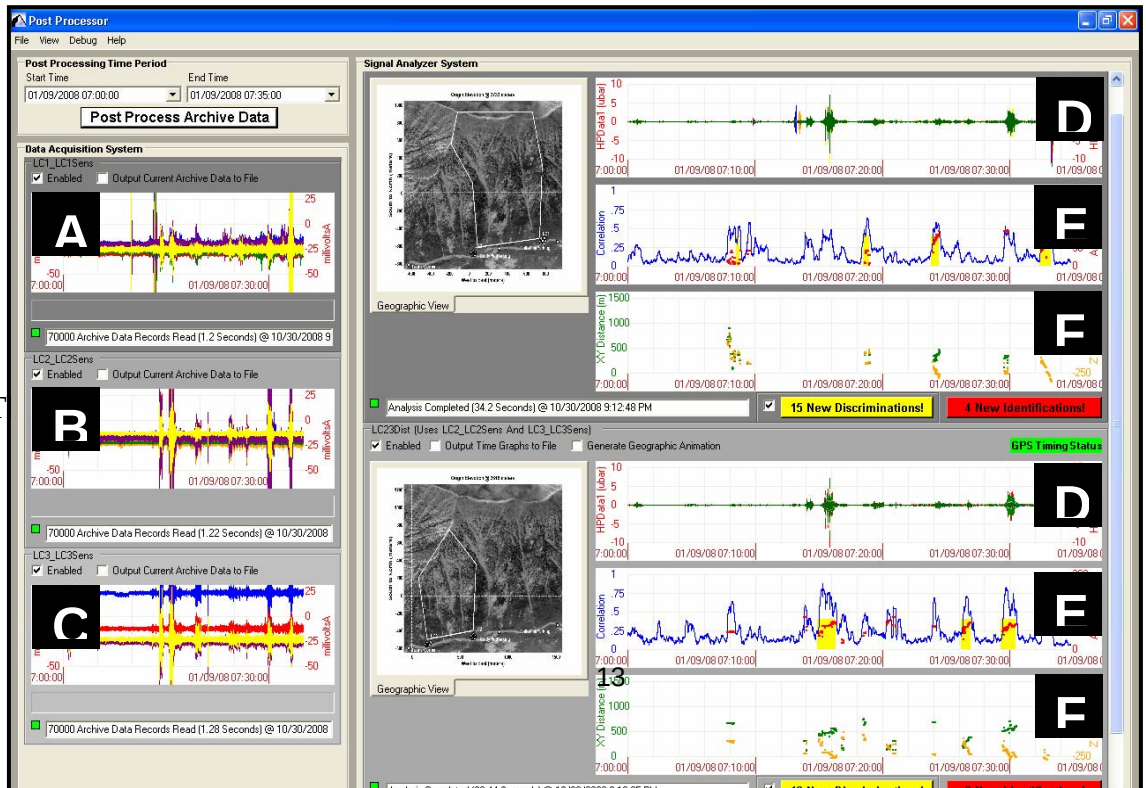
infrasound signal must persist for a given period of time. For example, detonation of the ammunition used in avalanche control also creates an infrasound signal, but its duration is extremely short when compared to the time that elapses during an avalanche. Infrasound signals for major avalanche activity can frequently last a minute or longer. Another criteria is correlation among the sensor arrays. Each sensor array has six sensors, all of which should detect the infrasound signal of a major avalanche. Occasionally only one sensor on the array detects an infrasound signal. Sometimes this is highway noise, and other times it can be local interference with the sensor, such as wildlife in the vicinity. If only one of the six sensors on the array detects an infrasound signal, then the rate of correlation between the sensors is low and the event is classified as "discriminated" and rejected as potential avalanche activity. Another major criteria is the x and y coordinates (or azimuth) of the detected signal. If the detected signal moves in a top-to-bottom direction along one of the avalanche paths, it will be classified as an "identified" avalanche event. If the detected signal is scattered at random across the hillside, or moves from bottom-to-top along a path, it will be classified as a "discriminated" interference event.

### 4.2 Infrasonic Case Studies in Little Cottonwood Canyon, 2008

The Little Cottonwood Canyon forecasters provided historical data from avalanche events monitored by the Infrasonic. This section is a case study of two separate data events logged by the Infrasonic: a natural avalanche cycle occurring on January 9, 2008, and controlled avalanche activity on January 21, 2008. This section describes how the Infrasonic is used on a typical day, and how it is integrated into the forecasters' decision-making process.

<u>January 9, 2008: Natural Avalanche Cycle</u>

Figure 8 shows a screen capture of the Infrasonic's graphic user interface, viewed daily (and sometimes several times daily) by the Little Cottonwood Canyon forecasters.

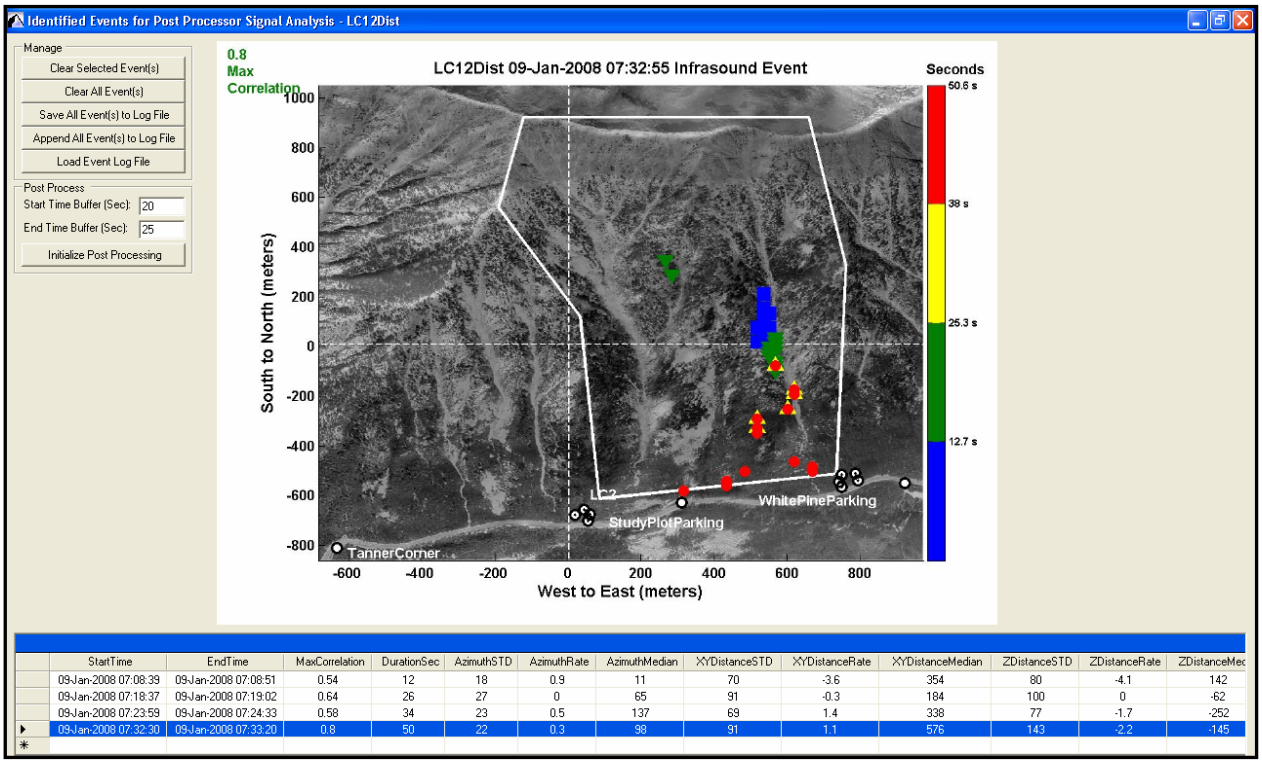


- Split screens analyzing the data for the two geographic areas being monitored (White Pine/Little Pine, and White Pine Chutes 1-4), as shown in the right two-thirds of the screen capture
- Infrasound signals for each geographic area (D)
- Correlation of infrasound signals from each sensor array to indicate how strongly they align with each other (E)
- Azimuth data indicating the path of travel for each infrasound signal (F)
- Red button indicating "identified" avalanche events, based on the parameters described in Section 4.1 of this document
- Yellow button indicating infrasound events that do not meet pre-defined criteria for avalanche activity, classified as "discriminated" events

The Little Cottonwood Canyon forecasters view this screen every morning as they prepare for the day's operations. For example, on the morning of January 9, 2008, the Infrasonic indicated four new natural avalanche events on the White Pine/Little Pine slide path, between 7:00 – 8:00 a.m. As shown in Figure 9, the areas of yellow in the correlation graph identified four avalanches based on the infrasound noise detected, where the noise occurred, and the degree of correlation among the infrasound detections of all the sensors.

**Figure 9: Signal Analyzer from Infrasonic User Interface, January 9 2008**

Upon clicking the red button for new avalanche events, the forecasters could view a screen indicating the geographic location of the identified avalanche events, including information on the duration and vertical length of the avalanche. An example is shown in Figure 10.




| StartTime | EndTime | MaxCorrelation | DurationSec | AzimuthSTD | AzimuthRate | AzimuthMedian | XYDistanceSTD | XYDistanceRate | XYDistanceMedian | ZDistanceSTD | ZDistanceRate | ZDistanceMed |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 09-Jan-2008 07:08:39 | 09-Jan-2008 07:08:51 | 0.54 | 12 | 18 | 0.9 | 11 | 70 | -3.6 | 354 | 80 | -4.1 | 142 |
| 09-Jan-2008 07:18:37 | 09-Jan-2008 07:19:02 | 0.64 | 26 | 27 | 0 | 65 | 91 | -0.3 | 184 | 100 | 0 | -62 |
| 09-Jan-2008 07:23:59 | 09-Jan-2008 07:24:33 | 0.58 | 34 | 23 | 0.5 | 137 | 69 | 1.4 | 338 | 77 | -1.7 | -252 |
| 09-Jan-2008 07:32:30 | 09-Jan-2008 07:33:20 | 0.8 | 50 | 22 | 0.3 | 98 | 91 | 1.1 | 576 | 143 | -2.2 | -145 |

**Figure 10: Image Output from Infrasonic Graphic User Interface, January 9 2008**

The image indicates an avalanche in the Little Pine slide path. The color scale denotes the passage of time: blue points are located where the first infrasound signals were detected, and red points indicate where the last infrasound signals were detected. The highlighted line in the table below the image shows that the avalanche began at 7:32:30 a.m. on January 9, 2008, and ended at 7:33:20 a.m. for a duration of fifty seconds. The image shown in Figure 10 not only helps forecasters determine the location of avalanches, but also eliminates false positives from consideration. For example, helicopters will be detected by the Infrasonic and identified as avalanche activity. However, helicopters will typically appear as a horizontal line across the image, allowing the forecasters to remove these events from consideration.

According to UDOT and IML records from January 9 2008, heavy snow had fallen the previous night – 22 centimeters, or around 8.5 inches. The Little Cottonwood Canyon forecasters initially saw no slabbing characteristics in the snowfall, and UDOT allowed SR-210 to stay open. However, wind speeds increased significantly between 6:30 a.m. and 7:00 a.m., and the Infrasonic began indicating a natural avalanche cycle. Since the Hellgate/Superior section of SR-

210 was closed, no one was in the office at Lower Guard to view the avalanche activity on the Infrasonic. Ernie Scott (the developer of the Infrasonic at IML) had a notification system set up, whereby he received text messages from the Infrasonic if avalanche activity was detected. Beginning at 5:20 a.m. on January 9 2008, the remote messaging system began notifying Ernie Scott via text message that avalanche activity was taking place. Ernie Scott began relaying this information back to Liam FitzGerald, who was not at Lower Guard at the time. The Hellgate/Superior section of SR-210 was closed to vehicle travel at about 7:00 a.m, and the road was closed at the canyon's mouth at 7:45 a.m. At this point, vehicles were already on the roadway. A natural avalanche occurred at Little Pine, narrowly missing one car and one bus. Upon clearing the canyon of vehicles, avalanche operations were conducted, with results being somewhat less than expected (possibly because much avalanche activity had occurred in the natural cycle prior to control).

January 21, 2008: Controlled Avalanche Activity

The same user interface is used for detecting both natural and controlled avalanche activity. Figure 11 provides a screen capture showing controlled avalanche activity from January 21, 2008.

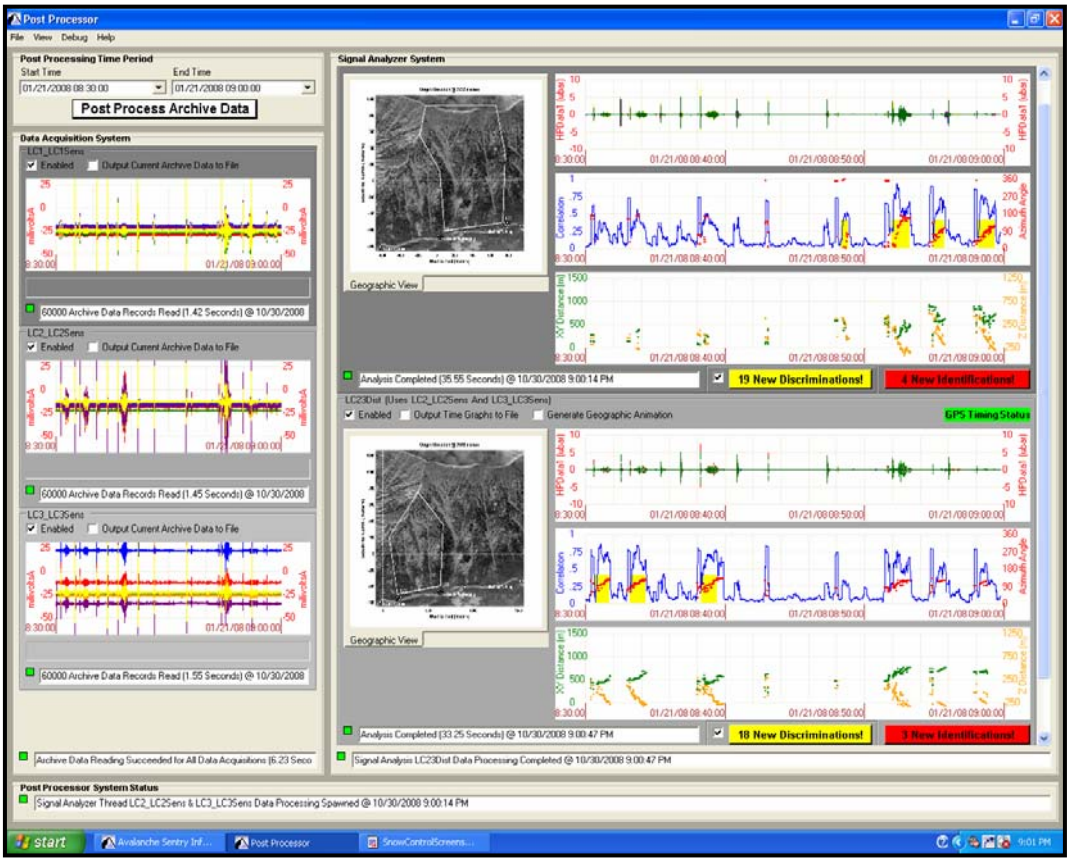



**Figure 11: Infrasonic User Interface Screen Capture, January 21 2008**

Figure 12 demonstrates the unique Infrasonic fingerprint of controlled avalanche operations. The noise of the ammunition detonating produces a sharp jump in the correlation graph, generally followed by a pattern of activity recognized by the Infrasonic as an avalanche.

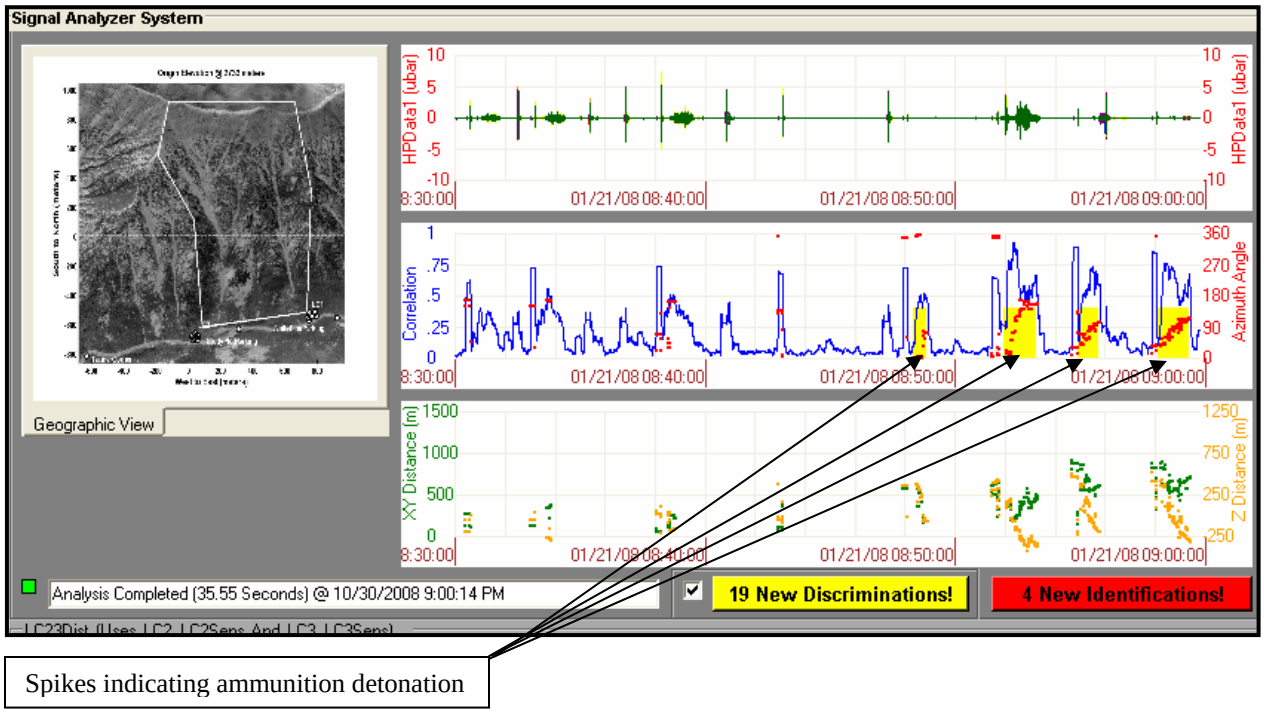



**Figure 12: Signal Analyzer from Infrasonic User Interface, January 21 2008**

As shown in Figure 12, the Little Cottonwood Canyon forecasters could track control operations on the Infrasonic, to determine which operations had been successful in triggering avalanches. For example, Figure 13 shows the image output from the Infrasonic system, indicating an avalanche that was triggered at 8:52:03 a.m. on January 21, 2008, and lasted until 8:53:20 a.m. for a total duration of 77 seconds.

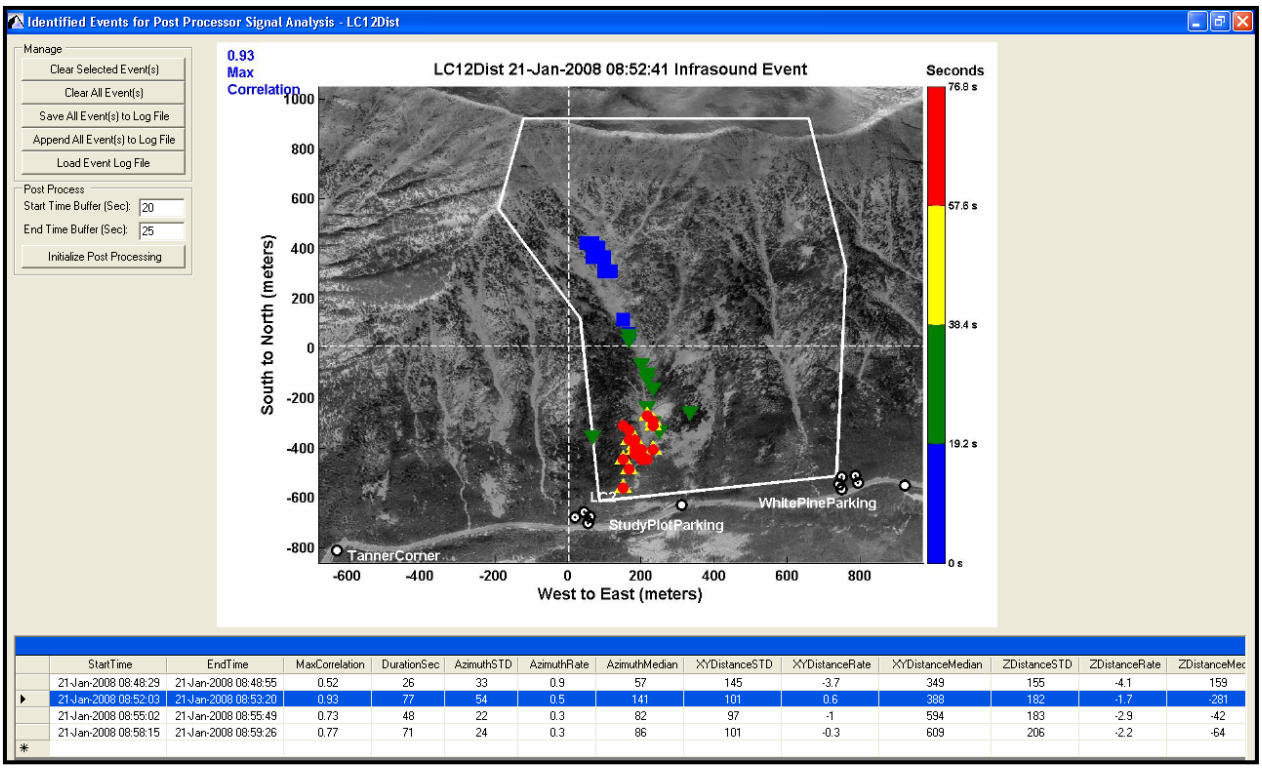



**Figure 13: Imagery Output from Infrasonic User Interface, January 21 2008**

The imagery and the data from this screen allow the forecasters to be relatively confident in their efforts. According to the forecasters' logs for January 21, 2008, the Hellgate/Superior section of SR-210 was closed beginning at 6:00 a.m., and the road was closed at the mouth of the canyon at 7:30 a.m. As shown in the figures, the Infrasonic provided sufficient confirmation of successful control operations to allow UDOT to confidently open the road after 9:30 a.m. to accommodate skier traffic.

### 4.3 Evaluation of Effectiveness

As mentioned in Section 3 of this document, several stakeholders were interviewed to gain their perspective and understanding of the Infrasonic. These included the Little Cottonwood Canyon forecasters, a UDOT forecaster from Provo Canyon, the developer of the Infrasonic, and a WYDOT forecaster who has used the Infrasonic in Teton Pass since 2002. The primary purpose of the interviews was to determine whether the Infrasonic provided early warning of natural avalanche cycles, and whether it provided confirmation of avalanche control operations. Secondary questions sought to ascertain what improvements might be needed for the Infrasonic, whether it was user-friendly, and whether it should be expanded to other locations (and if so, where those locations might be). This section summarizes stakeholder responses to these questions.

Does the Infrasonic provide reliable early warning of natural avalanche activity?

The Little Cottonwood Canyon forecasters unanimously agreed that the Infrasonic provided early warning of natural avalanche cycles. Jamie Yount of WYDOT separately confirmed that the Teton Pass Infrasonic has been very valuable for providing early warning of cycles, particularly when weather or snowpack conditions are changing rapidly and the avalanche hazard is increasing. Furthermore, Ernie Scott of IML provided additional confirmations of the system's advance warning functionality. Ernie Scott was intimately involved in the design and operations of the Infrasonic, and received text messages to his cell phone from the system during the 2007-2008 avalanche season when the Infrasonic detected avalanche activity. Ernie Scott would then contact Liam FitzGerald to discuss the output of the system; several times, Ernie's communication from the Infrasonic system was the first indication the Little Cottonwood Canyon forecasters received that natural avalanche activity was occurring.

Does the Infrasonic confirm avalanche control operations?

The Little Cottonwood Canyon forecasters, as well as Jamie Yount with WYDOT, all agreed that the Infrasonic confirms the efficacy of avalanche control operations. Unless control operations triggered slides that reached the road, the Little Cottonwood Canyon forecasters previously had few ways of confirming whether control efforts were successful, particularly if visibility was poor due to light conditions or weather. The only way for the forecasters to know if control was successful was to physically go out and monitor the slide paths, which puts UDOT staff at risk. The Infrasonic allows the forecasters to know, in real time, whether the ammunition hit the target; whether the ammunition detonated; and whether the detonation triggered an avalanche. The forecasters now have one person stationed at the user interface at Lower Guard during control operations, who reports to control operators whether efforts were successful. This allows the Little Cottonwood Canyon forecasters to make control decisions in real time: whether to re-shoot certain targets, or whether a lack of triggered avalanches indicates a relatively stable snowpack. Furthermore, the knowledge provided by the Infrasonic allows the forecasters to make more informed decisions about highway closures. Ernie Scott indicated that on January 21, 2008 (discussed previously in this report), the information disseminated from the Infrasonic allowed the forecasters to know that avalanche activity had been successfully triggered in Little Pine, even though they could not observe this visually firsthand, and this knowledge led to the decision to open SR-210 sooner than it would have been otherwise. Normally the road would have remained closed until further avalanche activity was triggered, or until the team was able to visually verify that avalanche control operations were successful.

Does the Infrasonic system reduce UDOT costs?

The Infrasonic system likely reduces costs for UDOT, although these costs are currently difficult to quantify. First, the Infrasonic improves human costs in terms of safety for the traveling public.

The Infrasonic improves safety by providing better information to UDOT staff regarding the need for road closures. The Little Cottonwood Canyon forecasters can develop better knowledge about potential avalanche conditions: whether more avalanche control is needed, or whether the snowpack is considered to be stable. This reduces the risk for UDOT in opening the road for traffic; alternately, it provides UDOT with the knowledge needed to keep the road closed for further avalanche control operations.

Second, the Infrasonic improves human safety costs for UDOT avalanche control staff. In the past, if the forecasters could not verify whether control operations in White Pine or Little Pine had been successful, their choices were either to assume the risk and open the road, or send someone out to verify in the field. This meant sending a UDOT staff person along SR-210 to the slide paths to see whether avalanche debris had hit the road, or whether avalanche activity was visible elsewhere on the slide path. This staff person would be in immediate danger of avalanche, not only from White Pine and Little Pine but also from the other slide paths along SR-210, since White Pine and Little Pine are mere indicators of a canyonwide avalanche cycle.

Third, the Infrasonic can potentially reduce the duration of road closures, which represents an economic benefit to the ski resorts in Little Cottonwood Canyon. When UDOT has better information available about whether avalanche conditions are safe enough to open the road, it can allow traffic sooner than it might otherwise. This represents less economic impact to the resorts. While research is fairly limited on the economic impacts of road closures, some information is available. According to Road Closure: Combining Data and Expert Opinion (Blattenberg and Fowles, 1994), the economic implications of road closures on ski resorts are significant. For the 1991 – 1992 ski season, average daily traffic on SR-210 was 5,710. Each of these vehicles had an average of 2.6 persons per vehicle, 2.5 of which were assumed to be skiers. Of these skiers, 40% tended to be residents, who spent an average of $19 per day at the ski resorts; 60% tended to be non-residents, who spent an average of $152 per day at the ski resorts. Using these figures, a road closure during the 1991 – 1992 ski season meant the loss of $1,410, 370 per day in revenue for the resorts. This amount would be higher in 2008 dollars, given inflation rates and cost increases for lift passes and lodging.

Fourth, the Infrasonic enhances efficiency of avalanche control operations in Little Cottonwood Canyon. The Infrasonic provides near-real-time confirmation of avalanche control efforts: within ninety seconds, staff at the artillery can know whether efforts were successful or whether a target should be re-shot. Previously, if it was not known whether control efforts were successful, the avalanche forecasting team would have to discuss the merits of shooting again or accepting the results of the previous effort. Furthermore, UDOT has limited supplies of ammunition, and does not wish to waste those supplies. The immediate knowledge provided by the Infrasonic allows the control operations to proceed more quickly, leading to a shorter duration of road closures.

Shorter road closures require less time from both UDOT staff and the Utah Highway Patrol (UHP), which assists in canyon sweeping efforts and controlling traffic at the base of the canyon.

Bill Nalli, the UDOT forecaster for Provo Canyon, provided an estimated cost for each canyon road closure. UHP mans the closures and sweeps the canyon in numerous places: two off-road vehicles sweep the bike path that parallels to the road, and four other patrolmen are out on the corridor. A total of seven patrolmen in vehicles are needed to conduct closure, and UHP charges UDOT $1,500 per event for a closure, assuming a five-hour mission. UDOT tries, when possible, to have intermittent closures during control work, so it doesn't impact traffic as much. If natural avalanches aren't threatening the road but control work may threaten the road, UDOT will shoot for 15 minutes, have UHP ensure the roads are clear, and then let traffic through. Then UDOT and UHP close the road for another 15 minutes and repeat the process. Along with the time needed for control work, UHP needs roughly two hours of setup time to do sweeps (contact the ice climbers, check the parking areas, talk to homeowners, and other tasks). A five-hour mission assumes the intermittent closures plus pre-control sweep time. In addition, each control effort costs $4,500 costs for UDOT man hours and artillery in addition to UHP closures.

Should the Infrasonic system be expanded? If so, where?

The UDOT forecasters unanimously agreed that the system's usefulness justifies expansion. In Little Cottonwood Canyon, several locations were identified for system expansion: above the Town of Alta; Snowbird Village; between Little Pine and Snowbird Entry 4; or Slide Canyon in Provo Canyon. Jamie Yount indicated that while WYDOT has invested significant funds since 2002 into the Teton Pass Infrasonic system, they currently do not have plans nor funding for expansion. However, should funding become available, they would consider pursuing an Infrasonic array at the Cow of the Woods slide path in Hoback River Canyon, 18 miles south of Jackson.

In general, there are several important criteria for successful Infrasonic arrays, should the system be expanded:

- Ability to place sensor arrays on either lateral side of the targeted avalanche path
- Ability to place the sensors to close proximity to the targeted avalanche path if detection of small (in addition to large) avalanche events is desired
- Ease of access to the sensor arrays
- Ability to accommodate the "footprint" required for a sensor array (the six sensors used in each Little Cottonwood Canyon array needed to be about 20 meters apart)
- Robust radio communications link between sensor arrays and the CPU

- On-site charging of the sensor array's 12-volt power supply (addressed via on-site solar panels at the Little Cottonwood Canyon arrays)

### 4.4 Comparable Systems

Several comparable remote monitoring systems are in place around the globe. These include a wider-range infrasound monitoring system, ground-based radar, and geophones; in the past, UDOT has used a track sensor device in Little Cottonwood Canyon as well. These technologies are described in the following paragraphs.

Arfang

The Arfang performs infrasound detection of avalanche activity. It uses a four-sensor system to determine the location and intensity of avalanches detected. It also provides an audible sound file of the avalanche activity, transposed from the infrasound data. The Arfang is manufactured by IAV Engineering, a Swiss firm based in Tannay, and the device is used in Zermatt, Switzerland. Similar to the Infrasonic, the Arfang allows detection of avalanches complementary to the usual visual methods of observation. IAV provides an online database of avalanches that have occurred near one of their detectors, plus the infrasound detection of explosions as well as other infrasonic events. A limitation of the Arfang is a high susceptibility to noise confusion (mistakenly classifying ambient noise events such as wind, helicopters, or highway traffic as avalanche events). This requires more interpretation on the part of human readers to differentiate between avalanches and other events.

Ground-Based Synthetic Aperture Radar

Ground-Based Synthetic Aperture Radar (GB-SAR) uses radar to monitor avalanches and snow cover stability. The system consists of a sled carrying antennas and a network analyzer back and forth over a short rail, aiming at an avalanche path and acquiring one image every ten minutes in its full aperture and one image every 2.6 seconds in a sub-aperture. The full ten minutes are necessary to get a new picture of the area, which means that human viewers receive refreshed information every ten minutes. The GB-SAR avalanche application is limited to one experimental system put together by the Joint Research Centre in Ispra, Italy. The system is located in the Sionne Valley, in the Canton Valais, Switzerland. The GB-SAR does not require placement directly in or near avalanches, but can be placed in a location with adequate visual or radar access to avalanche

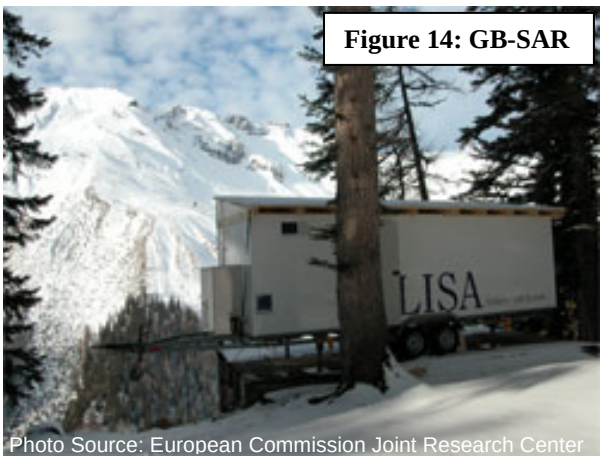


Figure 14: GB-SAR
Photo Source: European Commission Joint Research Center

paths. At this point, the system appears to be experimental, likely intended for academic use rather than practical application. It has a high rate of false negatives (not reporting avalanches that have occurred), particularly during bad weather when background noise is high due to falling snow.

Track Sensor

The track sensor has a steel cable strung across the track portion of an avalanche path, at a height preventing it from getting struck by avalanche debris. Attached to this steel cable is a control cable which runs from the control box (a box containing circuit boards, batteries, and a VHF radio) to a sensor suspended vertically from the midpoint of the steel cable. The sensor is intended to get hit by the avalanche. When it gets hit, it swings outward. The sensor contains a mercury switch which, when the sensor swings to more or less horizontal, closes and completes the circuit back to the control box. When the circuit is completed, the power from the batteries depresses the transmit button on the radio, and a recorded message is broadcast indicating that the track sensor has been activated. The recorded message is broadcast over the Alta Marshall Dispatch (Alta Central) radio channel. The track sensor was manufactured by Gasman Industries, a Canadian company, and is likely not in use in any other location besides White Pine Chute #1 in Little Cottonwood Canyon. The track sensor works well, is easy to troubleshoot, and has minimal costs. However, it will give false positives (indicating avalanches when there are none) in windy conditions. Also, devices such as this are prohibited from installation in the wilderness areas present in Little Cottonwood Canyon.

Geophones

A geophone detects ground motion and converts it into voltage to be measured at a recording station. Geophones typically consist of a spring-loaded magnetic mass contained within a wire coil. They are frequently used by oil and mining companies for seismic exploration. Several companies within the US manufacture geophones for various purposes, including GeoSpace, Mitcham Industries, and GISCOGEO. However, few, if any, of these manufacturers appear to have products specifically for avalanche monitoring. The available documentation on avalanches and geophones indicates their use for measuring propagation speed of avalanches, for the purpose of estimating the mass needed for protective structures in Ryggfonn, Norway. In addition, Washington State DOT used geophones near Snoqualmie Pass to measure glide avalanche activity and study how glide avalanches form and release. In neither case are geophones used for the purpose of real-time avalanche monitoring as is needed in Little Cottonwood Canyon.

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# 5.0 CONCLUSIONS

The Infrasonic system meets expectations of UDOT avalanche forecasters, and is exemplary in providing good information about natural and controlled avalanche activity in Little Cottonwood Canyon. The system provides early warning of natural avalanche cycles, and confirms control work on several fronts: whether ammunition detonated, whether it detonated in the intended location, and whether it triggered avalanche activity. Other comparable monitoring systems are not appropriate in this application due to limitations in transmission time, compatibility with wilderness restrictions, or product development for avalanche monitoring. Overall, the Infrasonic has excellent utility for Little Cottonwood Canyon, and the system users interviewed for this research evaluation felt it needed very few functional improvements. However, some concerns still linger. The issues discussed in this section include ongoing software management, communication, and transferability.

## 5.1 Ongoing Software Management

While the UDOT Little Cottonwood Canyon forecasters are very adept at maneuvering through the Infrasonic interface and interpreting the information it provides, only Ernie Scott of IML is familiar enough with the system's software and programming to troubleshoot problems. Ernie has been instrumental in the development and deployment of the system, and he spent much of the 2007-2008 season retooling the system's software to make it operate more efficiently. In addition, he is compiling a user's manual for the Infrasonic that should be delivered to UDOT before the end of 2008. However, should IML discontinue the Infrasonic program and its associated support services, UDOT lacks the technical expertise to continue to maintain, fine-tune, or expand the system. Indeed, it is likely that no one besides Ernie Scott has the depth of understanding of this system and of infrasound technology related to avalanches needed to continue as technical support to UDOT. While the Infrasonic's "help" menu in the software provides information on the parameters used to define avalanche criteria, this technology is so unique and relies so heavily on Ernie Scott's knowledge gained through experience that it may not easily transfer to another person. Furthermore, while UDOT owns a license for the Infrasonic post-processing software, it cannot legally change the code. This continues to be an ongoing issue with the Infrasonic.

## 5.2 Communication

The Little Cottonwood Canyon forecasters agreed that radio notification of the Infrasonic's avalanche identifications would be useful, as it could be broadcast to all forecasters simultaneously. The current system of text-messaging to a cell phone (which currently only

Ernie Scott receives) has limitations in Little Cottonwood Canyon, where several locations lack cell phone service due to the steep and enclosing canyon walls. Such a system would provide instant notification of avalanche activity to all Little Cottonwood Canyon forecasters, without requiring a person to be seated in front of the computer in the office.

Other concerns about the system's communication relate to bandwidth limitations. Communication from the sensor arrays to the CPU at Lower Guard is routed through a serial port, which limits the amount of data that can be transmitted. Also, communication from the sensor arrays does not have a direct line of sight to Lower Guard, which inhibits the transmission of data. Furthermore, the CPU at Lower Guard can only receive data from the three sensor arrays sequentially, not simultaneously, which limits the speed at which the data can be transmitted, processed, and presented to the forecasters.

### 5.3 Transferability

Both the Teton Pass and Little Cottonwood Canyon Infrasonic systems were developed through research and development efforts. IML received grants from the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation (NSF), and the Wyoming Department of Transportation (WYDOT) to develop the Infrasonic. Both systems have undergone significant transformations as development continued over the years. UDOT (and presumably WYDOT) staff have had to adjust to frequent changes in the system, as the Infrasonic was refined over time. At this point, the Little Cottonwood Canyon Infrasonic is considered complete, and IML is compiling a user's manual for its clients. Given the amount of research and fine-tuning that has already transpired around the Little Cottonwood Canyon Infrasonic, some economies of scale should be present in future expansions in Little Cottonwood Canyon. However, transferability with those same economies to another state DOT or perhaps even another canyon (i.e., Provo Canyon) within UDOT's jurisdiction is unknown.

In addition, as previously mentioned, much of the knowledge needed to set up, manage, and refine an Infrasonic system is limited to IML. Should IML discontinue their work in infrasound monitoring, the value of the Infrasonic to UDOT may be very limited. UDOT's avalanche forecasters are adept at seasonal setup of the sensor arrays as well as reading and interpreting the output from the system, but lack the technical expertise to handle software problems. Furthermore, it is not known at this point if IML intends to continue providing support services, if support services will be gradually terminated but UDOT will be trained in the code programming of the Infrasonic, or whether services will be terminated and UDOT will not be provided any further software training. Transferability is assured only if IML provides training to UDOT technical staff in the programming and development of the Infrasonic. UDOT would prefer to have an ongoing service contract with IML to address programming issues.

## 6.0 RECOMMENDATIONS/IMPLEMENTATIONS

This research evaluation makes the following recommendations for the Infrasonic system.

- Consider expansion of the Infrasonic system in Little Cottonwood Canyon in Snowbird Village and possibly Hellgate/Superior, if these conditions are met:
    - UDOT shall have the legal right to alter the software's programming codes
    - The user's manual (anticipated for delivery in December 2008) shall be adequate to meet training needs for individuals new to the system, and the manual shall also address troubleshooting hardware and software issues.
    - An economy of scale should apply in expanding the Little Cottonwood Canyon Infrasonic, because:
        1. UDOT staff is already familiar with the use of the Infrasonic user interface and does not require further training from IML
        2. Field work for set up, take down, and maintenance can be completed by UDOT staff
        3. UDOT has already purchased a software license
    - IML shall provide training to UDOT IT staff on software programming as well as hardware troubleshooting.
- Alternately, in lieu of items A through E above, IML shall be contractually obligated to continue provision of support services to UDOT as needed, and commit to continuing the Infrasonic program for a number of years into the future.
- Consider adding an Infrasonic in Provo Canyon at the Slide Canyon path. Economies of scale may not be as applicable here: while the same UDOT staffers will be utilized for set up, take down and maintenance, a Provo Canyon system will likely require more involvement from IML for communication links, system design, and possibly additional software license purchases.
- Make notification possible via radio broadcast, rather than via cell phone or text message. If radio notification is not an option, arrange for all UDOT Little Cottonwood Canyon forecasters to receive text message notification of identified avalanche events.
- Fine-tune the parameters for avalanche classification, to reduce the number of small avalanches that are falsely classified in the "discriminated" interference bin.
- Consider expanding use of the Infrasonic to traveler information systems. For instance, posting Infrasonic results online may help communicate avalanche and road closure conditions to the traveling public, reducing congestion at the base of the canyon during road closures. It may help the traveling public decide whether to recreate in a different canyon on road closure days, or wait until avalanche control operations have concluded before heading to Little Cottonwood Canyon.

- Continue evaluating materials options for the sensor hoses, which have a tendency to become frozen in winter and cease functioning.
- Evaluate the potential to improve the radio link between the sensor arrays and the CPU at Lower Guard. The current link is marginal, which occasionally (though infrequently) results in failure during data collection from the sensors.
- Establish an ongoing maintenance procedure at the sensor arrays for clearing brush, which will make access to the sensors easier.

The following table provides a priority ranking and a timeline for implementation items.

**Table 2: Implementation Actions**

| Action | Priority | Timeframe |
|---|---|---|
| Obtain legal right to manipulate software | High | Winter/Spring 2009 |
| Obtain training from IML for UDOT IT staff | High | Winter/Spring 2009 |
| Radio notification of avalanche events for UDOT crews (Liam, Paul, Chris, and Adam) | High | Winter 2009 |
| Consider Infrasonic expansion at Snowbird Village | High | Summer 2009 |
| Review user's manual for functionality | Medium | Spring 2009 |
| Consider Infrasonic expansion at Hellgate/Superior | Medium | Within next 3-5 years |
| Consider Infrasonic expansion at Slide Canyon | Medium | Within next 3-5 years |
| Evaluate hose materials | Low | Within next 5 years |
| Evaluate radio link improvements | Low | Within next 5 years |
| Establish ongoing brush maintenance | Low | Summer/Fall 2009 |

# APPENDIX A: STAKEHOLDER INTERVIEWS

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## Infrasound Monitoring Research/Evaluation Interview Template

**Name**: Bill Nalli Agency/Representing: UDOT, Provo Canyon Avalanche Control

**Date:** October 22, 2008, 9:00 AM

1) General impressions of the Infrasonic system? Was this the first time you'd seen it?

Bill saw the Infrasonic system up close for the first time this October. He had seen some of the research papers and the computer interface, but hadn't seen the equipment up close. Bill's impression is that it has a lot of potential to help with forecasts and seems like a good tool, providing that they learn how to use it. The learning curve is a limitation but not one that's unattainable. It may seem daunting at first to people unfamiliar with electronics and computers in general. However, Bill has seen a market change in people's ability to use technology, with staff being able to use it more. More and more, people coming into his field of work seem to have some degree of technological aptitude. Those that are comfortable with learning computers in general are going to be able to pick up on it. Many new job candidates have technical training specific to the field. Adam Naisbitt, for example, has a degree in GIS and this is becoming more common in applicants. These staff members would probably be more comfortable learning the Infrasonic technology.

2) Are you aware of any other infrasound or remote sensing systems that we should be comparing the Infrasonic to?

   Bill doesn't know of anything else out there like this. He remembered that at 2000 ISSW there was a study in progress on geophones. The study seemed to be in its infancy at the time, and he hasn't seen anything about it since. Other than that, he isn't aware of any other infrasound or remote sensing technologies.

3) Would the Infrasonic be of use to you in Provo Canyon?

In Provo Canyon, the avalanche paths are much bigger and longer running. The 3 main paths have a vertical fall of over 5400', and linear distance is about 12,000'. The road is in the runout zone, and avalanches that reach the road would have to be huge in order to affect the road. During storms the key part of Bill's forecast is whether smaller natural avalanches have occurred. For instance, in the morning, has a deep slab built up, or is the slab only half the thickness it would have been because there was a natural avalanche? This information is a huge factor in whether they do avalanche control or not.
The primary use of the Infrasonic system in Provo Canyon would be to identify natural avalanche activity. Bill doesn't have that ability right now. He can guess, or wait until after the storm and look, if visibility permits. The infrasound system would identify whether there were avalanches in key locations, which indicates whether they need to do control work in the other areas of concern. There are locations, one specifically, where it would be applicable. When Ernie first started his research, he had the Infrasonic system in Provo Canyon, trying to identify avalanches in Slide Canyon (adjacent to Sundance, one of the major avalanche paths and one

of the three major avalanche paths in the state that affects a road). However, Ernie didn't get enough data because of the lower frequency of events. Ernie needed lots of data in a small amount of time to further his research, and had to relocate it elsewhere. Slide Canyon would still be a good candidate for infrasound monitoring, though. They could use one infrasound system in Provo Canyon to monitor Slide Canyon, and that would be all they really need. If they knew what's going on in Slide Canyon, they could infer likely avalanche activity in the rest of Provo Canyon.

The infrasound system would also help them verify detonation of artillery rounds. They have 3 different drainages that they shoot artillery at, and only one is relatively close. In the others, they're shooting at indirect locations and the distance and topology prevents them from hearing the report.

Bill had an idea of potential costs for closure missions. UDOT uses UHP to do closures. UHP mans the closures and sweeps the canyon in numerous places – they have two 4-wheelers that sweep the bike path that runs parallel to the road, then they have 4 other patrolmen that are out on the corridor. A total of 7 patrolmen in vehicles are needed to conduct closure, which costs UDOT $1500/event for a closure, assuming a 5-hour mission. UDOT tries, when possible, to have intermittent closures during control work, so it doesn't impact traffic as much. If natural avalanches aren't threatening the road but control work may threaten the road, UDOT will shoot for 15 minutes, have UHP ensure the roads are clear, and then they let traffic through. Then UDOT and UHP close the road for another 15 minutes and do it all over again. Along with the time needed for control work, UHP needs a couple hours of setup time to do sweeps (get the ice climbers; check the parking areas, homeowners, etc). 5 hours assumes the intermittent closures plus pre-control sweep time. Then there are $4500 costs per control effort for UDOT man hours and artillery in addition to UHP closures.

## Infrasound Monitoring Research/Evaluation Interview Template

**Name:** Liam FitzGerald Agency/Representing: UDOT

**Date:** October 23, 2008

1) Did the Infrasonic provide early warning of natural avalanche activity?

Yes. There are two particular instances that Adam should be able to look up in the Infrasonic's data archive: the first week of February 2008 (possibly the 7th), and sometime in January 2008 (possibly around the 11th). The January event was a slide at Little Pine that reached the road. In both instances, the Infrasonic picked up on natural avalanche activity as it occurred.

2) Did the Infrasonic verify avalanche control efforts?

Yes.

3) How many false positives or negatives have occurred?

Not very many. In the area that the Infrasonic covers well (White Pine, White Pine Chutes, and Little Pine), the system is pretty reliable. It probably doesn't detect small avalanches that occur above White Pine Chute #4, because it doesn't receive enough data. Liam doesn't know of any false positives (where the system identified avalanches that didn't actually occur) nor of false negatives (where the system missed avalanches that did occur), but it's more likely that false negatives occurred than false positives.

4) How does the Infrasonic tell you if an avalanche has occurred, and can that process be improved?

The system samples data every 120 seconds. If, within that 120-second span, it detects something defined on the pre-set parameters as an avalanche event, it puts the relevant data into a bin reserved for avalanche events; everything else gets put into a "discriminated" bin, meaning it doesn't fit the defined parameters for an avalanche. In the morning, Liam comes into the office, looks at the Infrasonic's computer interface, and reviews the data in both the "avalanche" bin and the "discriminated" bin. This is the only consistent way to receive notification of avalanche events. Ernie has his cell phone set up to receive notification of events, but no one else has this available currently. Ernie frequently logs onto the computer interface at Lower Guard to tinker with the program, and sometimes when he's doing this he sees evidence of avalanche activity. If he sees this, he usually calls Liam to inform him.

5) What are the pros/cons of the communication system?

It would be nice if automated notification of avalanche events could be sent to Liam and his staff via radio. Cell phone notification would not be effective in Little Cottonwood Canyon due to the presence of cell service "dead zones", where no coverage is available because of the mountain topography. In the past, the track sensor UDOT used to monitor one of the White Pine Chutes would send signals to UDOT staff over the radio system, which everyone had access to.

6) Are you aware of other infrasound monitoring systems we should be looking at?

Liam knows someone who uses GeoPhones. He suggested looking through prior ISSW conferences to find other examples beyond what we already know about (Ar-Fang, radar, Infrasonic, etc).

7) How can the Infrasonic system be altered to improve results?

It takes some training in the system to retrieve the data and maximize the system's potential. Liam hopes the user's manual (expected for completion this year) will address these issues in addition to troubleshooting. They've had the system in place since January or February of 2007, but that was such a dry season that they didn't get many opportunities to use the Infrasonic system. It's taken most of a year to become trained in the system, and Adam has picked it up remarkably quickly. Ernie's periodic visits have helped them through the learning curves, but his visits have come to a close and UDOT staffers are now on their own. WYDOT seems to be in a similar situation.

8) Does the Infrasonic save time in avalanche control operations?

Not necessarily. UDOT chose the Mid-Canyon area for Infrasonic applications because the White Pine, White Pine Chutes, and Little Pine slide paths hit the road much more frequently than other slide paths hit the road. For instance, the Mid-Canyon slide paths hit the road three or four times a year, whereas slides above the Town of Alta hit the road once every several years. Therefore, Liam's crews spend more time working on the Mid-Canyon paths than they do anywhere else, and having additional information available to them via the Infrasonic helps them make better decisions about control on these paths. It doesn't necessarily save time, but it does give them better information and improves their safety. They don't typically have enough staff available to devote one member to computer monitoring. However, if they had enough staff members to have someone watching the monitors at Lower Guard and reporting back via radio to the control crews as to whether control operations were effective, that would probably save time.

9) Would an expanded Infrasonic system be useful?

Yes. The next place for an Infrasonic array should be above the Town of Alta. Slides in this location run to the roadway less frequently than in Mid-Canyon, so staff is less aware of avalanches taking place in this area because the evidence isn't visible. Toledo, Flagstaff, and Emma Ridges are all good candidates for Infrasonic in this area.

10) Has the Infrasonic system reduced road closures or the duration of road closures?

Yes. Once last year, Paul was watching the monitors while the ski resorts were shooting at White Pine. Liam was on the road and couldn't tell whether any avalanches had been triggered, but he talked to Paul and Paul said he saw some detected on the Infrasonic. This additional information, in real time, allowed them to make a decision to keep the road open because they knew avalanche control operations had been effective.

11) How does the Infrasonic affect the cost of avalanche control operations?

It can verify whether shots were effective, or whether more rounds need to be fired. If the shot was effective and the Infrasonic verifies it, they know they don't have to fire again. Without the Infrasonic, they might complete extra shots to be safe, which means additional costs in terms of artillery used. Keeping the road open is preferable economically for the resorts as well, since they have continued access to customers with the roads open.

**Name:** Jamie Yount, WYDOT avalanche forecaster, answers to questions transmitted via email,

**Date**: 10/27/08

1) Does the Infrasonic give you early warning of natural avalanche activity? Yes. The system can identify smaller avalanche events that indicate the onset of natural avalanche activity. This information is extremely valuable for the WYDOT avalanche team when weather or snow pack conditions are changing rapidly and highway avalanche hazard is increasing.

2) Does the Infrasonic verify avalanche control efforts? Yes. Having the infrasonic system allows us to verify avalanche control efforts in darkness and during poor visibility. Before the infrasonic system, control results during darkness or poor visibility could only be verified if avalanche debris reached the highway.

3) How might the Infrasonic system be improved? The infrasonic system on Teton Pass uses single sensor array monitoring compared with the distributed array monitoring used in Little Cottonwood Canyon. The Teton Pass system performs well but could be improved with the addition of another array for distributed monitoring.

4) How does avalanche control differ for infrasound-monitored paths compared to other paths? Infrasonic detection provides information on artillery round locations, control work results, onset of natural avalanche activity, and estimations of avalanche size from the comfort and safety of an office computer. This information can only be gathered with field observations on other paths without infrasonic technology. These observations can be impossible to gather in poor weather or darkness and with state employees exposed to avalanche and weather hazards.

5) Does the infrasonic save time/cost in avalanche control operations? If so, how much? Using the system during avalanche control missions saves time in confirming avalanche control results and provides valuable information regarding highway safety for road open and closed decision making. I don't believe that there is a direct cost reduction to WYDOT but there is a cost benefit to the local economy when the highway closures are minimized. An example would be that control work is done on Teton Pass at 0300 during an intense winter storm. No avalanche results are observed at the highway but the infrasonic system show all monitored paths have slid but stopped short of the road. This gives the WYDOT avalanche team confidence to open the road as soon as control work is finished as the hazard has been reduced. The road has only been closed for an hour during off traffic hours with little disruption to the local work force or commercial truck traffic. If the highway remains closed the economic losses are around $10,000/hr for Teton Pass.

6) What criteria are important in identifying appropriate locations for infrasound? Infrasonic technology can be used at any location with an avalanche forecasting and control problem. The ideal location would be near a path that is seen as an "Indicator Avalanche Path" where avalanche activity would first initiate during a natural avalanche cycle.

7) Does WYDOT plan to add more infrasonic arrays? If so, where? WYDOT has made several large investments in developing infrasonic avalanche detection technology and has been involved with the project since 2002/2003. We feel our support has produced an extremely valuable tool that has proven itself to the avalanche community. With our current budget we are unable to invest any more money into infrasonic avalanche monitoring. However, if funds become available in the future a system is seen as desirable for the Cow of the Woods slide path in the Hoback River Canyon 18 miles south of Jackson.

8) Has the Infrasonic system reduced road closures or the duration of road closures? If so, how many times? Infrasonic technology has not reduced the number of closures but the system has significantly minimized the road closure duration. A rough estimate is that the system reduces the closure duration for about half of the seasons control missions.

## Infrasound Monitoring Research/Evaluation Interview Template

**Name:** Chris Covington Agency/Representing: UDOT Avalanche Forecasting, Little

Cottonwood Canyon

**Date:** October 28, 2008

1) How much have you used the infrasound system interface? If not very much, skip green highlighted questions.

Chris looks at it on a daily basis in the winter to see if it's reporting anything happening. On the occasions when it's showing an avalanche has happened overnight, the first thing to do is make everyone else working that day aware of the avalanche. If Chris sees the system before anyone else in the morning, he contacts the other forecasters. He tells them the magnitude of the avalanche reported by the system, and asks them what they think should be done.

2) Does the Infrasonic provide early warning of natural avalanche activity?

Yes. It's been really valuable for that.

3) Does the Infrasonic verify avalanche control efforts?

Yes. Those are probably two most valuable things it does {verifying avalanche control and providing early warning}. The forecasters have started stationing a person at the computer while they're conducting avalanche control, and having that person verify whether the control went off, whether it went off where they wanted it to, and whether it caused an avalanche. Before they only knew of avalanches that hit the road. The Infrasonic notifies them of avalanches before they start to hit the road.

4) How does the Infrasonic system tell you if an avalanche has occurred, and can that process be improved?

It lights up a new identification tab on the screen which is very visible and very easy to see. Clicking on a few buttons then provides a picture of the terrain, showing where and how big the avalanche was. It is quite easy to interpret, and quite easy to know when the system is telling you something. The only thing that would make it more useful is if it had some way to call the forecasters on a cell phone. Currently the system requires a person in front of the screen to see the results and interpret them. If it could broadcast a call over the radio or a cell phone, then they would have immediate knowledge of avalanche activity without sitting in front of the screen.

5) What are the pros/cons of the system's communication?

The main issue is that it does require being where the screen is. More immediate, electronic, constant (radio/phone) device notification would be great. The changes that were made last winter to the communication links seem to have resolved some issues they were having related to communication. During the winter of 2006/2007, the system used a radio system that broadcast from the site to a relay, then to the office. Data transmission was spotty and slow. Time lags were significant: by the time control results had shown up on the screen, the controllers would have moved on to the next target to keep control operations moving. Last season that was changed to a direct line from the site to the office. They never lose the system

now. There is about a minute and a half between when they shoot and when it's verified.

6) Are you aware of any other infrasonic or remote sensing systems?

Chris knows that Newell was looking into geophones several years ago, but he doesn't know of anything else.

7) How can the Infrasonic system be altered to improve results?

Other things would be very small, incremental improvements. Ernie has talked about the hoses, which have become frozen in the past. An improvement would be to find better materials that measure the pressure change but don't let in moisture. Ernie explained that two of the sensors at some point last year stopped working; he thought it was because they were frozen. It wasn't a critical issue because they had so many sensors.

8) How does avalanche control differ for infrasound-monitored paths compared to other paths?

Chris wouldn't say it's significantly different. They just have the advantage of being able to say with confidence whether the control work was successful. In practice, one difference is that they end up shooting targets more than in the past, because the Infrasonic has showed them that an avalanche wasn't successfully triggered or the bullet didn't land in the right place. In the past, or on other paths without the Infrasonic, they would have shot once and lived with the result.

9) Does the infrasonic save time in avalanche control operations? If so, how much?

It's better to think of the system as increasing safety: speed in control operations doesn't matter if it hasn't accomplished anything. It saves time because the person who's in the office during control can verify where avalanches were triggered and how far they went. In the past, that was accomplished by someone driving down the road in a truck, below the paths, and looking up at them. That's a big time savings.

10) Would an expanded Infrasonic system be useful? If so, where?

It's certainly monitoring the most important paths right now. It is rare to have an avalanche cycle that doesn't originate in the paths currently monitored – those are almost always the first paths to have avalanches. Its other application of verifying control work could certainly be useful on every avalanche path which requires control. Another eligible location would be above the Town of Alta. There have been times in the past when big snowstorms continue for long periods of time, and visibility is limited or nonexistent. If the storm continues, there is no way to know whether an avalanche has come down unless they can see it on the road or somewhere else they can see. In that scenario, this system could be helpful in deciding when and where to shoot based upon if there has or has not been an avalanche. However, this is a rare scenario and Chris hasn't seen it himself. Liam would know when the last time that's happened.

11) Has the Infrasonic system reduced road closures or the duration of road closures? If so, how many times?

Chris thinks so, doesn't know how many times.

12) Is the system user-friendly? How can it be improved?

Yes.

**Infrasound Monitoring Research/Evaluation Interview Template**

**Name:** Paul Garske

**Agency/Representing**: UDOT Avalanche Forecasting, Little Cottonwood Canyon

**Date**: October 28, 2008

1) How much have you used the infrasound system interface?
Paul looks at the system on a daily basis. Every time they shoot the artillery, people up there are watching the system's results.
2) Does the Infrasonic provide early warning of natural avalanche activity?

Yes. It's demonstrated that it shows natural activity. 3) Does the Infrasonic verify avalanche control efforts? Yes. It verifies targets being hit by the bullets, and it verifies the activity from the artillery. 4) How does the Infrasonic system tell you if an avalanche has occurred, and can that process be improved? If Paul comes to the office and it's been snowing and he hasn't seen anything on the highway, he would walk into the office and the red button would be lit up. He would click on the red button to see how many "identifications" there are and how large they were. There were also the yellow buttons or "discriminations", where the Infrasonic wasn't sure how big the events were but they don't fit the criteria Ernie defined for avalanche activity. The system heightens their awareness of what's going on. They can look at red-button slides in depth, see when an avalanche started, and how far it ran. 5) What are the pros/cons of the system's communication? He thinks the way it works in the office is very good. They are currently working with Ernie to get text messages via cell phone so they can be notified in the field that the system has detected avalanche activity. 6) Are you aware of any other infrasonic or remote sensing systems? Paul knew geophones had been looked at in the past but didn't know of anything else. 7) How can the Infrasonic system be altered to improve results? With any high-tech systems, people are at the mercy of the equipment. When things go bad, they don't have the background that Ernie does. Ernie can look at the software and

fix things for them. The physical components of the system (hoses, etc) are still in the experimental stage and they're looking at different materials to make those more reliable. They had one or two sensors go bad recently, although the system still worked fine. The electronics at the sites will require troubleshooting if the equipment goes bad, and Paul doesn't feel qualified to troubleshoot. Adam is pretty computer savvy, but the more high-tech the harder it is to keep up. Ernie is also working on a flow chart and user manual that might make it more user-friendly.

8) How does avalanche control differ for infrasound-monitored paths compared to other paths?

Paul doesn't think it's different. What is different is that they are able to see results when it's snowing or it's nighttime and visibility is bad - they are able to look at those avalanche paths and have a good idea of what's going on. For instance, if they have to close the road in the afternoon, they'll shoot all the targets to protect the highway. For the infrasonic-monitored paths, they will be able to tell if bullets hit where they're supposed to and whether they triggered avalanche activity. They can then feel good about opening Mid-Canyon because they could verify whether activity occurred. In the past, if they had done that in the afternoon and they didn't see anything hit the road, they wouldn't know whether anything had been triggered. They'd then have a group discussion as to what to do next – ski checking first hand on similar paths, looking at weather forecasts, asking if they feel good enough about opening the road. It's shooting in the dark vs. having the nice warm fuzzy feeling because of the Infrasonic data.

9) Does the infrasonic save time in avalanche control operations? If so, how much?

Paul thinks it saves time after control operations, because they can use information from the Infrasonic and come to a decision sooner regarding highway closures.

10) Would an expanded Infrasonic system be useful? If so, where?

With an unlimited budget, it would be nice to have it in the whole canyon. To protect the highway, they should continue up the canyon towards Snowbird Entry 4. People can avoid slide paths higher up by using the bypass road, but they have to get off the bypass road and onto SR-210 via Entry 4 and then things get dicey. They can isolate Hellgate Superior and implement interlodge, at which point the road at Alta wouldn't be open anyway. People would just use the bypass road.

11) Has the Infrasonic system reduced road closures or the duration of road closures? If so, how many times?

Paul doesn't think it's reduced road closures but it may have reduced the duration of them. If they can see control results sooner, then they can make decisions sooner. If it's snowing a lot and they're thinking about closing the road, seeing things start to happen on the infrasonic may suggest closing the road earlier than they might have. On the flip side, when they've done control work they may open the road sooner because they've verified the results of the control work.

12) Is the system user-friendly? How can it be improved?

It's a highly technical program and software, and electronics are relaying the information through the radio. If something fails in those electronics, Paul doesn't know if anybody among their staff would be qualified to fix them. They have Ernie troubleshooting from afar, and they don't need it very often. They talk to Ernie every week or every two weeks; there might be a couple of times during the season that they really need help. It's mostly calling him up and telling him when they have activity, and making sure they're seeing things on the system the way they're supposed to be seen. Paul is personally very impressed with the system, and would like to see it everywhere if they had unlimited budget.

**Preface to questions 1, 2, and 3**: To assist me in answering questions 1, 2, and 3, I utilized the event logs I manually maintained to track avalanche activity detected by the infrasound monitoring system last season. I also used the event logs that the Near Real-Time Monitor automatically records during the detected signal classification process. From this information, along with my involvement in system operation last season, I was able to assemble the detected avalanche event summary tables placed at the end of this document. The suspected trigger for the events contained in these tables reflects my knowledge of what occurred last season in conjunction with my understanding of UDOT's LCC snow control operations. However, I was not always involved with UDOT LCC snow control operations and I do not have access to their records, so I cannot answer with 100% certainty what the triggers were for all of the detected avalanche events that were encountered last season. The accuracy of the information contained in the tables could certainly be cross checked with the records kept in conjunction with

UDOT's LCC avalanche program. For proper understanding of the tables and the responses to questions1, 2, and 3, please read the response to question 4 first. Reading the response to question 9 first would probably help too.

**1. Did the Infrasonic provide early warning of natural avalanche activity?**

Yes, early warning of natural avalanche activity was provided on many occasions. Information regarding the detected avalanche activity that was suspected to be naturally occurring is included in the tables at the end of this document. A discussion of natural activity that I have an intimate knowledge about is included below.

Starting December 19, 2007 the infrasound monitoring system began detecting the first avalanche events of the season. Detection of many avalanche events continued through the end of 2007. Many of these avalanche events occurred at night, which makes them apparently natural events, since UDOT does not perform LCC snow control activities at night. Throughout the remainder of the 2007/2008 season, it is safe to assume that the other encountered night time events were also natural events.

During the morning hours of January 9, 2008 a significant natural avalanche cycle occurred. I was actually working on site this week, so I got to experience and participate in this situation first hand. Prior to this natural avalanche cycle (i.e. during the early morning hours of January 9, 2008), closure of the highway to perform snow control activities was not deemed necessary. At 5:20 AM I was woken in Sandy by an avalanche event alarm notification sent to my cell phone. Another alarm notification dropped on my cell phone around 5:48 AM, which prompted me to get out of bed. I checked the status of the highway on the internet and was surprised to see that the highway was open without a scheduled closure to perform snow control. Around 6:48 AM I received another alarm notification on my cell phone, so I decided to call the UDOT LCC avalanche office and discuss the alarms I had received. During the initial words of this conversation, I received another alarm notification on my cell phone. Prior to my call, Liam (the only one who was on duty), had not viewed the systems central processing unit to recognize that the system believed there was natural avalanche activity occurring. Upon talking to me and checking the system, Liam checked weather conditions outside of the UDOT LCC avalanche office and he deemed that the avalanche alarms could certainly be accurate because conditions had changed drastically since the earlier decision to not schedule a highway closure or snow control. Thus Liam proceeded to initiate the procedures necessary to close the highway. At that time, I connected to the systems central processing unit via remote control capabilities and simply observed Near Real-Time Monitor operation. During the following half hour of system operation I watched numerous Near Real-Time Monitor avalanche detections occur. Some were classified as identified avalanches in the targeted monitoring region, while others were classified as discriminated interference. All the avalanche detections abruptly ended at around 7:35 AM. After watching the Near Real-Time Monitor for another half hour, I decided that it was safe to assume that the natural avalanche cycle had ended, so I called Liam to inform him of this perception. However, Liam was too busy to talk since the very last avalanche of the natural cycle was a Little Pine event that covered the highway while it was still open. I proceeded to use the Post Processor to investigate the avalanche detections that were classified as discriminated interference and found that many avalanche events were occurring throughout LCC, both in the targeted monitoring region and also outside of the targeted monitoring region. I think this day was the day that the system proved capabilities and value and every after the UDOT LCC avalanche crew utilized and relied upon it in a routine manner.

During periods of warm-up towards the end of the 2007/2008 season, the system detected naturally occurring wet slide avalanche events. Some of these were classified as identified avalanches in the targeted monitoring region, while others were classified as discriminated interference.

**2. Did the Infrasonic verify avalanche control efforts?**

Yes, verification of explosive snow control efforts occurred on a regular basis. Often during the same snow control mission, the system would confirm the successful explosive release of some desired avalanche events while also confirming the failure to explosively release some desired avalanche events. Due to the timing of avalanche detections contained in the event logs I maintained, it is believed that examples of such snow control missions can be found on the following days:

December 21, 2007
December 30, 2007
February 1, 2008
February 25, 2007
March 2, 2008

The aforementioned scenario of the January 9, 2008 natural avalanche cycle also provides an example of the system utility to verify snow control efforts. After the cessation of the natural avalanche cycle, two separate snow control missions were performed on this day. I personally sat in front of the systems central processing unit and observed Near Real-Time Monitor operation during these two snow control missions. Not one resultant avalanche event was detected during these two snow control missions. These results appeared to be reasonable, since the natural avalanche cycle could likely have already cleared the avalanche hazard and thus resulted in the lack of explosive released avalanche events. While I do not have knowledge of other control missions for which no avalanche events were successfully released, there certainly are other examples of such a scenario occurring during the 2007/2008 season.

Another example of the system providing value regarding the verification of snow control efforts occurred on January 21, 2008 when there was poor visibility and thus no ability to confirm snow control results through visual observations. However, the infrasound monitoring system verified that explosive snow control efforts resulted in the successful release of many avalanche events. It is my understanding that without this information the highway may have remained closed until either substantial activity or stability was observed by forecasters and/or weather permitted visual evidence. Such prolonged closures can result in significant economic loss to ski areas and businesses in the canyon

An additional example of system operation during explosive snow control efforts occurred on February 12, 2008. After several weeks of what seemed like the relentless delivery of avalanche alarm notifications to my cell phone, I had anticipated a break from the LCC avalanche activity due to the fact that weeks of stormy weather had finally cleared. To my great surprise, I received an alarm notification of an avalanche event occurring late in the afternoon of February 12, 2008. In my subsequent attempt to figure out what was “wrong” with the system, I was relieved to find out that UDOT had performed helicopter bombing, which had resulted in White Pine cornice drops.

As a final point, the infrasound monitoring system was routinely used to verify the detonation of explosive ordinance and whether the explosive ordinance actually hit the intended target. While the system was not specifically designed to detect and identify explosions, it was anticipated that there could be value in its capability to do such a thing. This was found to be true as the UDOT system users had a strong desire to verify the accuracy of their artillery shots and the existence of any unexploded ordinance (i.e. duds).

**3. How many false positives/negatives occurred?**

The signal analysis targeting Zone 1 produced one false positive avalanche event identification on 1/14/08 from what is suspected to be a flying object. Also in Zone 1, there were 18 false negative

avalanche event identifications along with 31 true positive avalanche event identifications. Additionally encountered were seven instances where the signal analysis targeting Zone 1 classified avalanche signals emanating from Zone 2 as a Zone 1 avalanche events. This quirky behavior was not deemed to be detrimental, since the avalanche signals did indeed emanate from the targeted mid-canyon region. If desired, alterations to the processing algorithm configuration could most likely correct this issue.

The signal analysis targeting Zone 2 produced one false positive avalanche event identification on 1/31/08, which was caused by two successive explosive signals. Also in Zone 2, there were 22 false negative avalanche event identifications along with 29 true positive avalanche event identifications.

Absent from the above, is a discussion of the effectiveness of the signal analysis that targeted Zone 3, which did not incur any false positive avalanche event identifications. A majority of the 100 avalanches show in the tables at the end of this document resulted in false negative avalanche event identifications from the signal analysis targeting Zone 3.
The believed primary cause of these false negative avalanche event identifications is that they were due to small avalanches that produced low amplitude infrasound signals that simply could not be detected by all three sensor array monitoring nodes. Due to this encountered behavior, the signal analysis targeting Zone 3 was utilized more as tool to investigate whether explosive snow control ordinance detonated and the location of the detonations. However, when Zone 3 signal analysis results produced positive avalanche event identifications, the results were considered highly trustworthy.

Please keep in mind that the above discussion pertains to only avalanche events that I actually know happened. There were likely many very small avalanche events that also occurred, but did not produce an infrasound signal that lent itself to detection. Fortunately, these very small avalanche events are not the type of events we have targeted for identifying. As you probably will notice through your involvement with this project, successful detection of infrasound signals is a very difficult thing to implement, while proper classification of detected infrasound signals is also a very difficult problem to find an adequate solution. The core parameters involved in infrasound monitoring tend to be highly variable, which is problematic.

**4. How does the Infrasonic system tell you if an avalanche has occurred, and can that process be improved?**

Once a near real-time data collection interval is completed from the three distributed sensor array monitoring nodes (i.e. LC1, LC2, LC3), a series of three signal analyses are performed. The first signal analysis uses LC1 and LC2 data to target the White Pine and Little Pine slide paths (i.e. Zone 2). The second signal analysis uses LC 2 and LC3 data to target the four White Pine chutes (i.e. Zone 1). The third signal analysis uses data from all three distributed sensor array monitoring nodes to target all 6 of the desired mid-canyon region slide paths (i.e. Zone 3 = White Pine, Little Pine and the four White Pine Chutes)

A signal analysis will first determine whether any coherent infrasound signal events have been detected amongst the various sensors utilized in the signal analysis. If it is determined that one or more infrasound signal events were detected, then the signal analysis will classify each detected signal event as ether an identified targeted avalanche event or as a discriminated interference event. This classification is done using event statistics related to the distribution of the estimated three dimensional location of a detected signal event. In simplistic terms, detected signal events that exhibit movement consistent with a targeted avalanche event are designated as identified avalanches while detected signal events that appear stationary are designated as discriminated interference.

During the signal event classification process there certainly is a potential to either falsely attribute interference as an avalanche (i.e. false positive avalanche identification), or vice versa falsely attribute an avalanche as interference (i.e. false negative avalanche identification). Since a signal analyses can easily be configured to adjust the signal event classification process, a decision was made to allow some tolerance of false negative avalanche identifications due to short traveling avalanches, while having little tolerance of any false positive avalanche identification occurrences. Thus, the goal was to have high confidence that any detected signal events assigned to the identified avalanche classification are indeed due to avalanches, while keeping in mind that any detected signal events assigned to the discriminated interference classification could potentially be due to small avalanche events.

Within the user interface software, visual alarming is provided by each signal analysis to indicate assignment of detected signal events to either the discriminated interference classification or the identified avalanche classification. For each signal analysis, a dedicated command button will flash yellow and report the number of new signal events that have been assigned to the discriminated interference classification. Likewise for each signal analysis, a dedicated command button will flash read and report the number of new signal events that have been assigned to the identified avalanche classification.

The user can then inspect the signal events assigned to either of the two classifications by clicking on the appropriate command button. Upon clicking the appropriate command button, a window appears that makes available the statistics utilized to perform the detected signal event classification and also a geographic image which shows the location of the detected infrasound signal source as it progresses across the event time period. This display utility allows the user to quickly verify that detected signals classified as identified avalanche events were indeed cause by avalanches, and it also allows the user to pinpoint the exact slide path from which the infrasound signal originated. Likewise the display utility allows the user to quickly evaluate the detected signals that were classified as discriminated interfering events, which provides a means for finding any false negative avalanche identifications that may have occurred during the signal event classification process.

After the user clicks on a signal classification command button, the visual alarm notification is considered acknowledged and the command button is reset to a color of green with a message to indicate that no new signal events have been assigned to the classification. The command button visual alarming will not again occur until another detected signal event is assigned to the classification

A special email alarm option exists for detected signal events that are assigned to the identified avalanche classification. Thus, in addition to the visual alarming offered by the command button, an external email can be sent to designated recipients to facilitate the early notification of detected signal events for which there is high confidence in the fact that the signal source is truly a targeted avalanche event. This provides a powerful and flexible notification capability since emails can be directed to mobile devices that have wireless data access (e.g. Blackberry, Palm Pilot, cell phone). As is displayed via accessing the command button visual alarming, the sent email alarm notification includes the statistics utilized to perform the detected signal event classification and also the geographic image which shows the location of the detected infrasound signal source as it progresses across the event time period. If the email alarm notification is directed to a recipient’s cell phone, then the sent alarm information is converted into a SMS text message format.

**5. What are the pros/cons of the system's communication?**

In regards to the radio transmission of data between the remote sensor array monitoring nodes and the

central processing unit: PROS

Facilitated via off the shelf commercial instruments that have a solid proven track history
Robust to interference
Relatively low power consumption
It works

CONS

The commercial datalogger communicates through a serial port, so data throughput is limited to 115000 baud
There is not line of site between the LCC sensor array monitoring nodes and the central processing unit, which contributes to a marginal radio communication link
Communication between the central processing unit and the three sensor array monitoring nodes occurs in a sequential manner (i.e. simultaneous communications are not possible)
Thus, the cons limit the practical realized near real-time interval (see question 9 for more information on the near real-time interval)

In regards to the external email alarm notification:

PROS

Can be sent to multiple email addresses
Email can be accessed via mobile wireless devices such as a Blackberry or Palm Pilot
The email is converted into a SMS text message if the recipient email address is indicative of cell phone service
The email notification arrives very quickly and can be accessed from afar.

CONS

Requires an internet connection at the central processing unit
Requires the use of a Simple Mail Transfer Protocol (SMTP) server. During last avalanche seasons operation, Inter-Mountain Laboratories, Inc. SMTP server was utilized, but for the upcoming avalanche season, UDOT will need to utilize their own SMTP server.
The sent email notification message can be lost in cyberspace due to possible failures along the internet path that the email must transverse

**6. Are you aware of any other infrasonic/remote sensing systems?**

A company in Switzerland (IAV Engineering) has developed an infrasound monitoring system (ARFANG) that targets avalanche activity. While I have limited knowledge of their efforts, it is believed that the system suffers excessive false positives due to a lack of methodology for classifying the source of detected infrasound signals. I also suspect that the system in deployed in a less than ideal manner that attempts to monitor too large of a geographic region, which complicates the problem of alleviating false positives. Also it is not know whether the system uses data acquired from distributed sensor array monitoring nodes during processing, which provides a marked improvement in results obtained from just a solitary sensor array monitoring node.

Many other infrasound monitoring systems exist across the globe. The most sophisticated are most likely deployed in accordance with Comprehensive Test Ban Treaty efforts for identifying infrasound caused by nuclear bomb use. Other infrasound monitoring systems are deployed for a variety of scientific research (e.g. volcanoes, tsunamis, auroras, tornadoes, covert military needs, intelligence, etc.). If there is interest in viewing other infrasound monitoring efforts, then I suggest a good starting point to be http://www.inframatics.org/.

**7. How can the Infrasonic system be altered to improve results?**

Since concluding operations of the LCC infrasound monitoring system during the most recent avalanche season, significant improvements have been made regarding the efficiency of signal processing and removal of software bugs. These efforts certainly will provide software which is easier to utilize. However, the ability to effectively use the full capabilities of the system is a function of the users comfort with computers. A skilled computer user that is able to understand the underlying infrasound monitoring concepts will be able to extract more useful information from the system than a computer illiterate individual that does not understand the underlying infrasound monitoring concepts. Along these lines, the end users should really be in a habit of routinely managing and keeping pertinent event logs organized. Simply stated, the system is a tool to be used by a human and the automated decision making accomplished by the Near Real-Time Monitor cannot be expected to replace the abilities of a human operator.

Since the LCC infrasound monitoring system was developed during research and development efforts, it has exhibited significant changes across the years that certainly introduced confusion to the end users. Now that the LCC infrasound monitoring system is in a final polished form, such changes will not be a source of future confusion. The current efforts of the development team are focused on providing thorough and complete system documentation to the end users. This should provide a step forward in the end users ability to maintain and effectively use the system. Additional focused training sessions would also provide improvements in the ability of the end users to effectively utilize the system as a valued tool.

The LCC infrasound monitoring system would benefit from an improved radio communications link. The current radio communications link is marginal, which causes occasional failure during data collection. Fortunately these data collection failures are not frequent.

The remote sensor array monitoring installation would benefit from clearing of excessive brush, which would make annual maintenance easier. Also improving the sturdiness of the towers used for mounting necessary instrumentation would improve the safety of performing annual maintenance tasks. Upgrading the utilized infrasound sensors to a newer enhanced model would also likely provide an improvement of overall system results, but this would require capital expenses.

A new signal event classifier could be developed to identify explosives, since the end users are using the system to verify the detonation and location hit of explosive ordinance. Currently the explosive signal events are assigned to the discriminated interference classification, which requires the end user too search and disseminate the discriminated interference events to extract information regarding explosives.

It is expected that there is ample room to improve the methodology of deploying the pneumatic wind noise reducing hose array that couples an infrasound sensor to the atmosphere. Problems with deep snowpack compromising the porous section of the sensor hose array have been observed during past research and development activities. For the upcoming avalanche season, a new methodology of deploying the sensor hose array has been implemented for a signal sensor at each of the three sensor array monitoring nodes. Recorded signal integrity will have to be monitored over the course of the upcoming avalanche season to evaluate the effeteness of this attempted improvement.

The end users need to routinely watch the data channels to ensure that they are operating properly. A data channel that is not operating properly will negatively impact signal processing results. The system has been designed with redundant data channels and the ability to easily remove a data channel from processing, but a person must still stay on top of whether a data channel begins to fail.

It is possible that data acquired during a single avalanche event will be retrieved across the boundary of two Near Real-Time Monitor iterations. Thus the data acquired during the single avalanche event would be processed by two of the Near Real-Time Monitor iterations, which could result in two indentified avalanche classifications and alarm notifications for a single long running avalanche event. If this scenario does indeed happen, then the end user should be able to recognize that it is only one avalanche event through interpretation of system results.

**8. What criteria are important in identifying appropriate locations for Infrasound?**

The practical functional range of the sensing equipment to targeted slide paths is a complex matter. Successful signal detection is impacted by a number of factors that include:

Dynamics/Physics of the avalanche event
Topographical effects on avalanche signal propagation
Meteorological effects on avalanche signal propagation
Masking effects by ambient noise and/or interfering signal sources

These variables will be different for each independent monitoring application, which results in the need for custom monitoring system configuration. Sensing equipment should be deployed at monitoring locations that maximize the probability of successful avalanche signal detection. Also, sensing equipment deployment must be facilitated in a custom manner that maximizes the effectiveness of signal processing algorithms to positively identify detected avalanche signals without falsely identifying interfering signals (e.g. wind, explosions, airplanes, helicopters, traffic, trains, natural phenomena, etc.) or being masked by ambient noise (e.g. wind, industrial activity, etc.).

In general, for applying infrasound monitoring to target snow avalanche activity, I believe that the following criteria are critical for success:

Ability to locate distributed sensor array monitoring nodes in a matter that "brackets" (i.e. on each lateral side of) the targeted avalanche paths

If detection of small avalanche events is desired, then locating the infrasound sensors in close proximity to the slide paths is necessary

Ease of access to the sensor array monitoring nodes

Ability to accommodate the "footprint" required by a sensor array monitoring node, which requires sensors to be spaced at around a 20 meter intervals

Ability to establish a robust radio communications link between the remote sensor array monitoring nodes and the central processing unit

Ability to charge the remote sensor array monitoring node 12 volt power supply; whether this is solar, wind, or AC

In order to justify the expense of deploying a system, potential applications must have significant issues that can be affected and impacted in a valuable manner

**9. How much real-time information does the system provide?**

The LCC infrasound monitoring system operates on a near real-time basis, where data from the remote sensor array monitoring nodes are retrieved in blocks for subsequent analyses and result presentation\alarming. The near real-time monitoring interval is configurable, and the system is currently using a 90 second interval to facilitate the near real-time iterations. This interval potentially could decreased, but the wireless radio communication links, which are used to transfer data between the remote sensor array monitoring nodes and the central processing unit, are less than ideal and thus the bottleneck dictating the near real-time interval that can be realized in a reliable manner.

True real-time information is not seen as a practical reality, since data processing would have to occur within the remote sensor array hardware that is facilitating the infrasound measurements, which would require significant custom hardware development. Plus it is questionable as to whether the signal processing algorithm could even be executed fast enough when embedded in hardware attempting to provide real-time results. Another complicating factor for attempting to implement true real-time processing is that data obtained from distributed sensor array monitoring nodes are necessary for implementing processing that does not suffer from excessive false positives. This means that the necessary multiple sets of data acquisition hardware residing at different locations effectively prevents the ability to embed the signal processing algorithm in the data acquisition hardware.

2007/2008 Season Avalanche Events Detected by the LCC Infrasound Monitoring System Signal Analysis LC23, which Targets the Four White Pine Chutes (Zone 1)

| Event Time | Duration (Sec) | Max Correlation | Suspected Trigger | Near Real-Time Classification | Slide Path | Comments |
|---|---|---|---|---|---|---|
| 12/20/2007 9:37 | 17 | 0.56837 | Natural | Discriminated Interference | WP-C1 | |
| 12/20/2007 18:35 | 30 | 0.90912 | Natural | Identified Avalanche | WP-C2 | |
| 12/21/2007 0:48 | 60 | 0.85725 | Natural | Identified Avalanche | WP-C1 | |
| 12/21/2007 1:42 | 40 | 0.69754 | Natural | Identified Avalanche | WP-C3 | |
| 12/21/2007 4:16 | 20 | 0.57488 | Natural | Discriminated Interference | WP-C3 | |
| 12/30/2007 14:08 | 54 | 0.77377 | Artillery | Identified Avalanche | WP-C3 | |
| 12/30/2007 14:12 | 53 | 0.71437 | Artillery | Discriminated Interference | WP-C3 | |
| 12/30/2007 14:32 | 54 | 0.77934 | Artillery | Discriminated Interference | WP-C1 | |
| 1/6/2008 13:49 | 86 | 0.78815 | Natural or Artillery | Identified Avalanche | WP-C4,WP-C1,WP-C2 | Near Simultaneous Events |
| 1/9/2008 5:20 | 44 | 0.81021 | Natural | Identified Avalanche | WP-C3 | |
| 1/9/2008 6:39 | 50 | 0.6156 | Natural | Discriminated Interference | WP-C1 | |
| 1/9/2008 6:48 | 57 | 0.75542 | Natural | Identified Avalanche | WP-C4 | |
| 1/9/2008 6:52 | 40 | 0.78685 | Natural | Identified Avalanche | WP-C3 | |
| 1/9/2008 7:15 | 86 | 0.87849 | Natural | Identified Avalanche | WP-C2 | |
| 1/9/2008 7:26 | 37 | 0.69468 | Natural | Identified Avalanche | WP-C4,WP-C3 | Near Simultaneous Events |
| 1/9/2008 7:29 | 63 | 0.80363 | Natural | Identified Avalanche | WP-C1 | |
| 1/14/2008 12:32 | 51 | 0.80893 | Natural or Artillery | Discriminated Interference | WP-C1 | |
| 1/14/2008 12:49 | 44 | 0.84444 | Natural or Artillery | Identified Avalanche | WP-C3 | |
| 1/21/2008 6:53 | 53 | 0.73632 | Natural or Artillery | Identified Avalanche | WP-C3 | |
| 1/21/2008 7:43 | 70 | 0.70953 | Artillery | Identified Avalanche | WP-C3 | No Visibility, so System Contributed to Highway Opening |
| 1/21/2008 8:30 | 58 | 0.83082 | Artillery | Identified Avalanche | WP-C2 | No Visibility, so System Contributed to Highway Opening |
| 1/21/2008 8:33 | 63 | 0.80194 | Artillery | Identified Avalanche | WP-C1 | No Visibility, so System Contributed to Highway Opening |
| 1/21/2008 8:38 | 93 | 0.72567 | Artillery | Identified Avalanche | WP-C1,WP-C2 | Near Simultaneous Events. No Visibility, so System Contributed to Highway Opening |
| 1/21/2008 12:18 | 59 | 0.79541 | Natural | Identified Avalanche | WP-C3 | |
| 1/23/2008 12:39 | 37 | 0.66923 | Natural | Identified Avalanche | WP-C2 | |
| 1/30/2008 6:24 | 27 | 0.66858 | Natural | Discriminated Interference | WP-C2 | |
| 1/30/2008 7:54 | 40 | 0.78788 | Natural or Artillery | Identified Avalanche | WP-C1 | |
| 2/1/2008 7:15 | 25 | 0.50699 | Artillery | Discriminated Interference | WP-C4 | |
| 2/1/2008 7:19 | 39 | 0.70518 | Artillery | Discriminated Interference | WP-C3 | |
| 2/1/2008 7:23 | 29 | 0.7374 | Artillery | Discriminated Interference | WP-C2 | |
| 2/1/2008 7:26 | 43 | 0.74327 | Artillery | Discriminated Interference | WP-C1 | |
| 2/1/2008 7:29 | 48 | 0.80606 | Artillery | Identified Avalanche | WP-C2 | |
| 2/4/2008 1:17 | 64 | 0.79588 | Natural | Discriminated Interference | WP-C3,WP-C2 | Near Simultaneous Events. Snow Reached Highway? |
| 2/4/2008 2:15 | 40 | 0.80422 | Natural | Discriminated Interference | WP-C1 | |
| 2/25/2008 7:34 | 30 | 0.56618 | Artillery | Discriminated Interference | WP-C4 | |
| 2/25/2008 7:36 | 43 | 0.6442 | Artillery | Discriminated Interference | WP-C3 | |
| 2/25/2008 7:43 | 54 | 0.76335 | Artillery | Identified Avalanche | WP-C1 | |
| 2/25/2008 7:47 | 62 | 0.84364 | Artillery | Identified Avalanche | WP-C1 | |
| 2/28/2008 13:16 | 48 | 0.74475 | Natural or Artillery | Identified Avalanche | WP-C1 | |
| 3/2/2008 7:09 | 43 | 0.73111 | Artillery | Identified Avalanche | WP-C4 | |
| 3/2/2008 7:23 | 59 | 0.84929 | Artillery | Identified Avalanche | WP-C1 | |
| 3/15/2008 6:11 | 23 | 0.59266 | Natural | Discriminated Interference | WP-C1 | |
| 3/15/2008 6:14 | 28 | 0.77722 | Natural | Identified Avalanche | WP-C2 | |
| 3/19/2008 14:49 | 65 | 0.64206 | Natural | Identified Avalanche | WP-C2 | Wet Slide? |
| 4/9/2008 17:23 | 69 | 0.54206 | Natural | Discriminated Interference | WP-C4 | Wet Slide? |
| 4/9/2008 17:43 | 54 | 0.7862 | Natural | Identified Avalanche | WP-C2 | Wet Slide? |
| 4/9/2008 19:34 | 94 | 0.71021 | Natural | Identified Avalanche | WP-C4,WP-C2 | Near Simultaneous Events. Wet Slides? |
| 4/13/2008 13:36 | 66 | 0.76609 | Natural | Identified Avalanche | WP-C3 | Wet Slide? |
| 4/13/2008 15:24 | 45 | 0.62398 | Natural | Discriminated Interference | WP-C4 | Wet Slide? |

2007/2008 Season Avalanche Events Detected by the LCC Infrasound Monitoring System Signal Analysis LC12, which Targets White Pine and Little Pine (Zone 2)

| Event Time | Duration (Sec) | Max Correlation | Suspected Trigger | Near Real-Time Classification | Slide Path | Comments |
|---|---|---|---|---|---|---|
| 12/19/2007 8:38 | 46 | 0.80511 | Natural | Discriminated Interference | WP | Avalanche Identification Occurred for LC23 Signal Analysis |
| 12/20/2007 12:19 | 38 | 0.6734 | Natural | Discriminated Interference | LP | |
| 12/20/2007 18:12 | 29 | 0.67062 | Natural | Discriminated Interference | WP | |
| 12/20/2007 18:25 | 56 | 0.8546 | Natural | Identified Avalanche | WP | |
| 12/20/2007 19:01 | 62 | 0.80085 | Natural | Discriminated Interference | LP | |
| 12/21/2007 7:59 | 77 | 0.73959 | Artillery | Discriminated Interference | WP | |
| 12/21/2007 8:04 | 75 | 0.84754 | Artillery | Identified Avalanche | LP | |
| 12/24/2007 23:19 | 50 | 0.84381 | Natural | Identified Avalanche | WP | |
| 12/24/2007 23:44 | 46 | 0.85666 | Natural | Identified Avalanche | WP | |
| 12/25/2007 0:21 | 35 | 0.76579 | Natural | Discriminated Interference | WP | |
| 12/25/2007 1:24 | 26 | 0.74359 | Natural | Discriminated Interference | WP | |
| 12/30/2007 4:26 | 61 | 0.71407 | Natural | Discriminated Interference | LP | |
| 12/30/2007 10:59 | 32 | 0.78205 | Natural | Identified Avalanche | WP | |
| 12/30/2007 11:10 | 48 | 0.87174 | Natural | Discriminated Interference | WP | |
| 12/30/2007 14:42 | 27 | 0.76461 | Artillery | Discriminated Interference | WP | |
| 1/6/2008 12:36 | 16 | 0.65336 | Natural or Artillery | Discriminated Interference | LP | |
| 1/6/2008 13:23 | 19 | 0.6663 | Natural or Artillery | Discriminated Interference | LP | |
| 1/9/2008 5:48 | 32 | 0.75715 | Natural | Identified Avalanche | LP | |
| 1/9/2008 6:35 | 28 | 0.58595 | Natural | Discriminated Interference | WP | |
| 1/9/2008 6:47 | 49 | 0.70437 | Natural | Discriminated Interference | WP | |
| 1/9/2008 7:07 | 63 | 0.52714 | Natural | Discriminated Interference | WP | |
| 1/9/2008 7:18 | 45 | 0.62908 | Natural | Discriminated Interference | WP | |
| 1/9/2008 7:23 | 42 | 0.58287 | Natural | Discriminated Interference | WP | |
| 1/9/2008 7:32 | 55 | 0.78587 | Natural | Identified Avalanche | LP | End of Significant Natural Cycle, Covered Highway While Open |
| 1/14/2008 13:28 | 14 | 0.58171 | Natural or Artillery | Discriminated Interference | WP | |
| 1/21/2008 8:52 | 77 | 0.89916 | Artillery | Identified Avalanche | WP | No Visibility, so System Contributed to Highway Opening |
| 1/21/2008 8:55 | 48 | 0.70268 | Artillery | Identified Avalanche | LP | No Visibility, so System Contributed to Highway Opening |
| 1/21/2008 8:58 | 71 | 0.72185 | Artillery | Identified Avalanche | LP | No Visibility, so System Contributed to Highway Opening |
| 1/28/2008 13:37 | 46 | 0.83074 | Natural or Artillery | Identified Avalanche | WP | |
| 1/28/2008 14:03 | 36 | 0.81065 | Natural or Artillery | Identified Avalanche | WP | |
| 1/30/2008 3:55 | 45 | 0.82816 | Natural | Identified Avalanche | WP | |
| 1/30/2008 22:39 | 52 | 0.73769 | Natural | Identified Avalanche | LP | |
| 2/1/2008 7:33 | 89 | 0.88432 | Artillery | Identified Avalanche | WP | |
| 2/3/2008 18:23 | 43 | 0.79552 | Natural | Identified Avalanche | WP | |
| 2/4/2008 2:05 | 51 | 0.85378 | Natural | Identified Avalanche | WP | |
| 2/7/2008 1:20 | 71 | 0.82765 | Natural | Identified Avalanche | WP | Covered Highway |
| 2/12/2008 17:45 | 38 | 0.68143 | Helicopter Bomb | Identified Avalanche | WP | |
| 2/25/2008 7:53 | 37 | 0.85571 | Artillery | Discriminated Interference | WP | |
| 2/25/2008 7:55 | 48 | 0.59856 | Artillery | Identified Avalanche | LP | |
| 2/25/2008 7:57 | 44 | 0.65114 | Artillery | Discriminated Interference | LP | |
| 3/14/2008 10:36 | 49 | 0.68522 | Natural | Identified Avalanche | WP | |
| 3/15/2008 6:26 | 37 | 0.66697 | Natural | Identified Avalanche | LP | |
| 4/2/2008 4:11 | 79 | 0.62205 | Natural | Identified Avalanche | LP | |
| 4/9/2008 15:03 | 72 | 0.50828 | Natural | Identified Avalanche | LP | Wet Slide? |
| 4/9/2008 16:31 | 28 | 0.61052 | Natural | Identified Avalanche | WP | Wet Slide? |
| 4/9/2008 19:04 | 79 | 0.65672 | Natural | Identified Avalanche | LP | Wet Slide? |
| 4/9/2008 20:54 | 65 | 0.74701 | Natural | Identified Avalanche | WP | Wet Slide? |
| 4/12/2008 11:57 | 34 | 0.5374 | Natural | Discriminated Interference | WP | Wet Slide? |
| 4/12/2008 13:18 | 34 | 0.529 | Natural | Discriminated Interference | WP | Wet Slide? |
| 4/12/2008 13:48 | 59 | 0.78711 | Natural | Identified Avalanche | LP | Wet Slide? |
| 4/12/2008 13:55 | 163 | 0.80925 | Natural | Identified Avalanche | WP | Wet Slide? |

**Infrasound Monitoring Research/Evaluation Interview Template**

**Name:** Adam Naisbitt

**Agency/Representing:** UDOT Avalanche Forecasting, Little Cottonwood Canyon

**Date**: October 30, 2008

1) How much have you used the infrasound system interface?

Adam uses the system regularly, possibly daily, and has an excellent understanding of how the system operates and how to interpret the data.

2) Does the Infrasonic provide early warning of natural avalanche activity?

Yes. On the morning of January 9 2008, there was light snow density and UDOT wasn't concerned about doing avalanche control. They decided to keep the road open and not do control for the time being. No one was in the office at the time, and Liam had gone down the road for something. It was overcast, and they couldn't see well. At the time, the crews didn't recognize the value of the Infrasonic system to indicate natural cycles. The Infrasonic had shown that avalanches were beginning to occur naturally starting at about
5:20 AM. The Infrasonic monitors three criteria to pinpoint avalanche activity: the correlation coefficient from the sensors, the azimuth of detected infrasound activity, and the duration of detected infrasound activity.

3) Does the Infrasonic verify avalanche control efforts?

Yes. The Infrasonic verifies control in two ways: if control was fired properly, and if it hit the target. The forecasters want to know that the ordnance met the target, and whether control options have been exhausted if they haven't successfully triggered an avalanche. The Infrasonic also verifies where the target hit, so they know not only whether the ordnance went off but also whether it went off in the right place.

4) Are you aware of any other infrasonic or remote sensing systems?

Geophones, and the track sensor that UDOT has used in the past.

5) How can the Infrasonic system be altered to improve results?

Adam would like to see the Infrasonic tied to a pager system, so the forecasters could be aware of infrasound results without having to be in the office. They could be out of the office for an hour and conditions could change drastically, and they would need to initiate interlodge, conduct sweeps, and other actions. It would be helpful if they didn't have to be looking at the computer screen to get that critical information.
Adam would also like to be able to identify wet slide activity. The Infrasonic's ability to detect

wet slides seems to be limited. The Infrasonic may be using pressure from dust clouds on dry slides to detect avalanches, which doesn't occur on wet slides because the snow is more cohesive. The Infrasonic does detect wet slides when they drop off rock bands or other precipices, and the resulting THUD shows up on the monitor.

6) Does the infrasonic save time in avalanche control operations? If so, how much?

It saves time in the decision making process. If they've shot and triggered an avalanche, or they've shot and no avalanche was triggered but the snow seems stable, they have better information on what to do next. It also gives them immediate information on what to do with other slide paths.

7) Would an expanded Infrasonic system be useful? If so, where?

Ideally the system would be expanded in the upper canyon, either at Superior or Hellgate. It would be good to know what's going on when the light is flat or visibility is otherwise limited. They don't worry as much about whether ammunition has hit the targets on Superior and Hellgate, because they're shooting at a direct angle in those locations compared to the oblique shooting angle for White Pine/Little Pine. Another option for an expanded system would be around Snowbird Village. Slides have originated in this area in the past, and hit the road. Hellgate is easier to manage because they can close SR-210 and keep the bypass road open, and can also mitigate with passive control. High Models tends to be an indicator path, as is Hellgate – they almost always get control results in those locations.

Placement criteria: in a straight line across the bottom of a path, in a somewhat clear area not blocked by ridges or something blocking the sound. They need a direct transfer of sound, and should avoid a placement where there is a noise source (such as a road) in between the sensors and the avalanche path.

8) Has the Infrasonic system reduced road closures or the duration of road closures? If so, how many times?

Yes, sometimes. During afternoon shoots, there were five or six times when the Infrasonic influenced the amount of time to keep the road closed. They use the Infrasonic now on every control mission, and have someone stationed at the computer screen while control is going on. 90% of the time now, the Infrasonic is used in deciding road closures.

9) Is the system user-friendly? How can it be improved?

You have to know about computers in general to be able to use the Infrasonic. For instance, a user must know how to navigate through a computer directory and browse for files. They must also be able to recognize different file types and extensions, and know what that means. Beyond that level of familiarity with computers, the remaining skills are limited to being able to look at the screen and click on the "identified" and "discriminated" buttons to evaluate potential avalanche activity. Changing settings and properties on the system gets more complicated, but Adam doesn't feel it's any more complicated than dealing with their dataloggers or with the weather data software.

When the software was first installed, the UDOT forecasters had a four-day training session with Ernie to learn the programs. Everybody took notes, and had turns using the software interface. Adam talks to Ernie about once every three weeks, because the software has been an ongoing development process. Sometimes Ernie calls Adam or the other forecasters to inform them of minor tweaks he's performed to the software.

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