PRACTICAL IMPLEMENTATION OF AVALANCHE INFRASOUND MONITORING TECHNOLOGY FOR OPERATIONAL UTILIZATION NEAR TETON PASS WYOMING

Ernest D. Scott*
Inter-Mountain Laboratories, Inc., Sheridan, WY

Christopher T. Hayward
Southern Methodist University Department of Geological Sciences, Dallas, TX

Timothy J. Colgan, Jerry C. Hamann, Robert F. Kubichek, John W. Pierre
University of Wyoming Department of Electrical and Computer Engineering, Laramie, WY

Jamie Yount
Wyoming Department of Transportation, Jackson, WY

ABSTRACT: Recent advancements in infrasound monitoring hardware and software for the detection and identification of avalanche-generated infrasound signals have resulted in operation of a prototype monitoring system targeting avalanche activity occurring in the problematic slide paths that impact Wyoming State Highway 22 near Teton Pass. Implementation of the technology was facilitated in a manner aimed at providing a practical operational tool for the Wyoming Department of Transportation's avalanche hazard mitigation program. Custom sensors coupled with novel array processing have exhibited robust performance to the deafening and detrimental affects of ambient wind noise. Occurrences of false positive identification of interfering infrasound signals as significant avalanche events have been virtually eliminated through data processing discrimination methods that are based on source location features of detected signals. Performance of the automated signal discrimination methods decrease with respect to small avalanche events that do not travel far, but small events are still recognizable in system results by a skilled human interpreter. A remaining challenge is to improve the reliability of the infrasound signal path between the atmosphere and the sensor, which is covered by a variable snow pack. Upon resolving signal path issues, the technology will have reached a mature and stable state that can easily be utilized by the avalanche practitioner in appropriate applications without the need for continued extensive research and development activities.

KEYWORDS: Avalanche monitoring, infrasound, signal discrimination, sensor array

1. INTRODUCTION

Many past research studies have shown that snow avalanches generate acoustic signals within a low noise band of the sub-audible infrasonic frequency spectrum (Bedard 1989, Bedard 1994, Bedard et al. 1988, Chritin, et.al. 1996, Scott and Lance 2002, Comey and Mendenhall, 2004). These low frequency infrasound signals have the ability to propagate kilometers from the avalanche source and provide a basis for developing wide area automated monitoring systems that can operate in locations unaffected by avalanche activity. Such avalanche monitoring systems hold the potential to provide valuable information for professionals charged with responsibilities related to avalanche activity. Especially useful is the ability of an infrasound avalanche monitoring system to compliment and verify results of avalanche hazard mitigation efforts.

*Ernie Scott, Inter-Mountain Laboratories, Inc., Sheridan, WY 82801; tel: 307-674-7506; fax: 307-672-9845; e-mail: escott@imlinc.com

2. STUDY BACKGROUND

Since investigations of infrasound sensor array signal processing capabilities conducted during the 2003/2004 winter season produced encouraging results (Scott et al. 2004), prototype near real-time infrasound sensor array avalanche monitoring systems were operated in close proximity to Teton Pass, Wyoming during the 2004/2005 and 2005/2006 winter seasons. These prototype monitoring systems were operated with the intent of providing the Wyoming Department of Transportation (WYDOT) with an informational tool to support their avalanche hazard mitigation program for Wyoming State Highway 22.

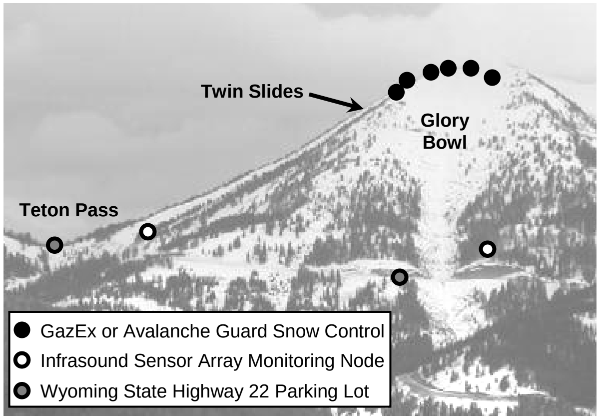

Figure 1. Teton Pass, WY Monitoring Setting

Figure 1 is an illustration of the Teton Pass monitoring area, which contains two major slide paths. Glory Bowl is the prominent slide path right of center. Twin Slides is apparent as the thin white sliver along the sky line left of center. Figure 1 includes markers representing landmarks contained in the targeted monitoring region. The summit of Mount Glory is near the black GazEx and Avalanche Guard markers, which designate snow control mechanisms used by WYDOT to induce avalanches. Grey markers are included that represent the parking lot at the top of Teton Pass near where Twin Slides crosses Highway 22 and the parking lot where Glory Bowl crosses Highway 22. Highway 22 traverses the grey parking lot markers.

The two white markers in Figure 1 designate sensor array monitoring node locations. Each monitoring node contained six custom prototype infrasound sensors that were optimized for avalanche signal detection. The infrasound sensors were deployed and measured in a similar manner as has been performed throughout the course of these experimental studies (Scott 2005).

3. RESULTS FROM MONITORING THE GLORY BOWL SLIDE PATH

Shown in Figure 2 are two instances of experimental results obtained from the sensor array located near Glory Bowl. Sensor array beamforming results obtained during a natural spontaneous Glory Bowl avalanche are overlaid on an Easting and Northing (i.e. XY) geographic view of the targeted monitoring region. Shown in the graphs are markers that correspond to the GazExs, Avalanche Guards, and Highway 22 parking lots that are contained in Figure 1. Additional markers designate the locations of the sensors contained in the Glory Bowl sensor array. Black to white colors (white being strongest) show the beam formed through array processing and are used to designate the existence and location of an infrasound signal that has been detected by the sensor array.

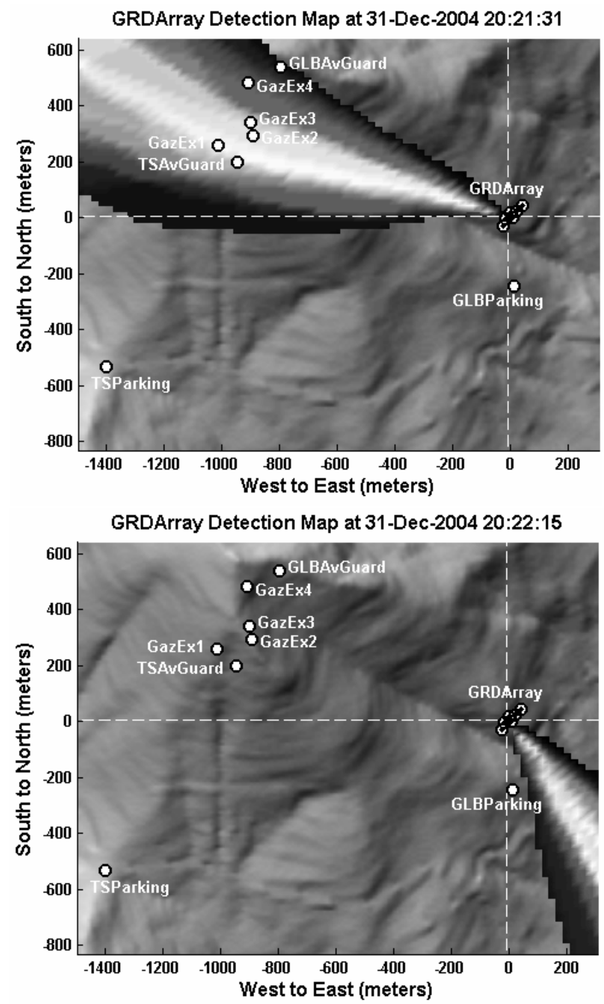

Figure 2. Glory Bowl 12/31/04 Beamforming

Evident in the top graph of Figure 2 is a beam, which indicates a signal is emanating from an azimuth angle consistent with the Glory Bowl start zone. The bottom graph shows beamforming results 44 seconds later, which indicates a signal detected by the sensors is emanating from an azimuth angle near the Glory Bowl run out zone. For the time period spanning the graphs, it is easy to envision how an animated sequence of beamforming results would show a beam that progressively sweeps through azimuth angles that are indicative of a signal emanating from an avalanche traveling down the Glory Bowl slide path.

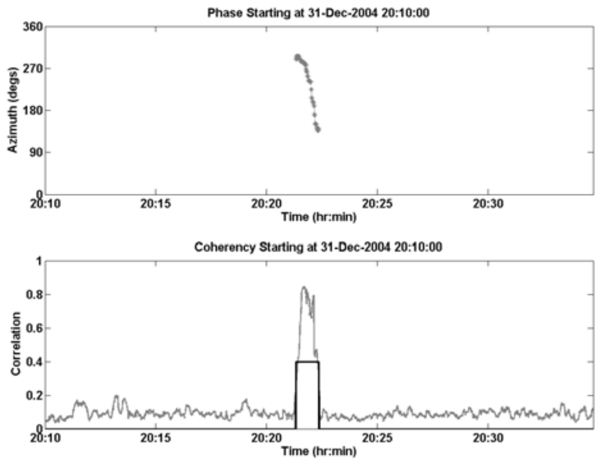

Figure 3. Glory Bowl 12/31/04 Feature Set

Since a comprehensive time progression of geographically displayed beamforming results is difficult to view in a static form, the strip chart visualization technique presented in Figure 3 was developed. This strip chart displays critical beamforming features across a thirty minute time period that contains the 12/31/04 Glory Bowl avalanche event.

The top graph in Figure 3 displays estimates of the azimuth angle of arrival for the infrasound signals detected by the sensor array. These azimuth angles are computed relative to the XY origin defined by the dashed white lines shown in Figure 2. A standard wind direction convention for defining azimuth angles relative to the XY origion has been adopted (i.e. 0/360º = North, 90º = East, 180º = South, 270º = West). The distribution and progression of azimuth angles clearly indicate that the detected signal exhibits a pattern consistent with movement of a Glory Bowl avalanche.

The bottom graph in Figure 3 displays information that represents whether a coherent signal has been detected by the various sensors contained in the array. Elevated values of correlation estimates in the bottom graph indicate that an infrasound signal has been detected by the sensor array, and provides a basis for automated threshold identification of the avalanche event (Scott et al. 2006). As shown by the black identification sequence in the bottom graph, the signal processing algorithm is able to automatically identify the avalanche event in a reliable manner by evaluating where correlation estimates exceed a threshold value of 0.4[1].

4. RESULTS FROM MONITORING THE TWIN SLIDES SLIDE PATH

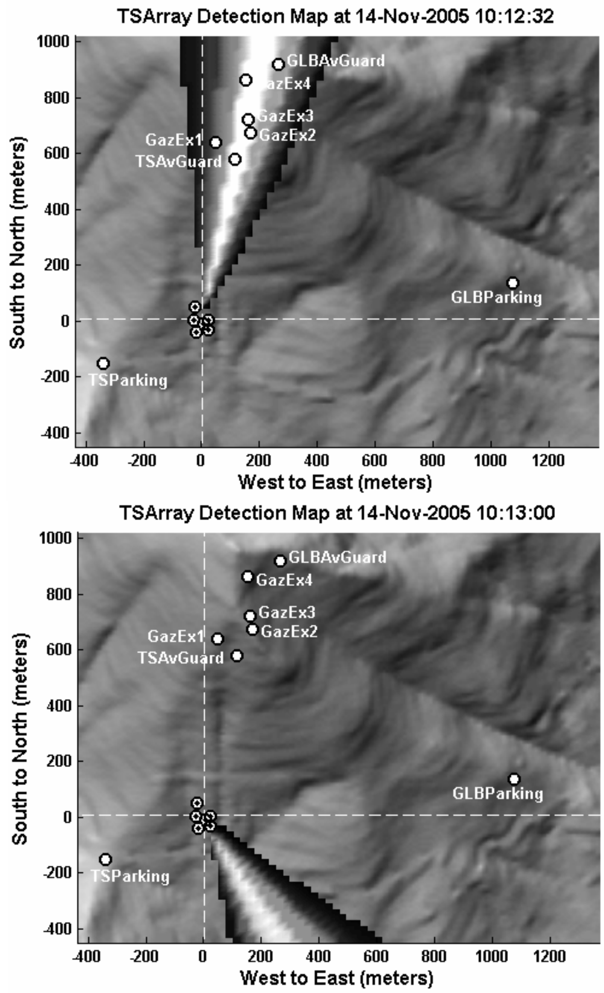

Figure 4. Twin Slides 11/14/05 Beamforming

Shown in Figure 4 are two instances of experimental results obtained from the sensor array located near Twin Slides. As was done for the Glory Bowl example shown in Figure 2, sensor array beamforming results obtained during a snowboarder triggered Twin Slides avalanche are overlaid on a geographic view of the targeted monitoring region.

Evident in the top graph of Figure 4 is a beam which indicates that a signal detected by the

[1] A non-zero identification sequence value indicates positive algorithm avalanche identification when using a threshold level that was set at the non-zero value.

sensors is emanating from an azimuth angle consistent with the Twin Slides start zone. The bottom graph shows beamforming results 28 seconds later, which indicates that a signal detected by the sensors comes from an azimuth angle near the Twin Slides run out zone. An animated sequence of beamforming results would show a beam that progressively sweeps through azimuth angles indicative of a signal emanating from an avalanche moving down the track of Twin Slides.

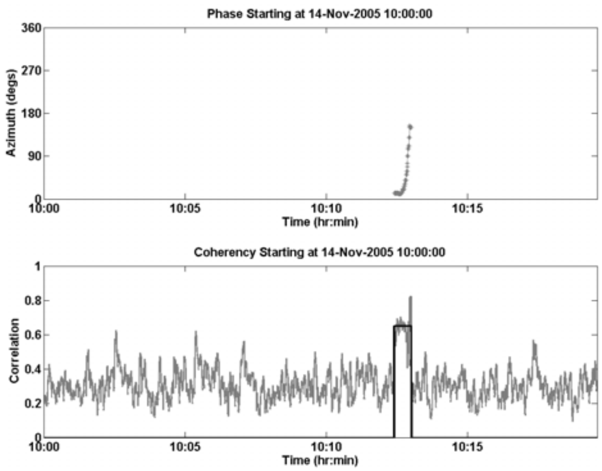

Figure 5. Twin Slides 11/14/05 Feature Set

Shown in Figure 5 is a compact strip chart visualization technique used to display critical beamforming features across a twenty minute time period that contains the 11/14/05 Twin Slides avalanche event. The distribution and progression of azimuth angle estimates in the top graph clearly indicate that the detected signal exhibits a pattern consistent with movement of a Twin Slides avalanche. The black identification sequence in the bottom graph shows that the signal processing algorithm is able to automatically identify the avalanche event by evaluating where correlation estimates exceed a threshold value of 0.65. However, in this example the reliability of the correlation threshold identification technique is marginal since the correlation estimate sequence exhibits elevated baseline noise that approaches the 0.65 threshold value.

5. IMPROVING AVALANCHE IDENTIFICATION RELIABILITY VIA LOCATION INFORMATION

As shown in the example above, the correlation estimates obtained from sensor array beamforming do not always provide a reliable basis for identifying detected infrasound signals as avalanche events. Depending on what level the correlation threshold is set, elevated noise can either result in false positive or false negative identification of an avalanche event. Additionally, interfering signals from non-avalanche sources can cause spurious correlation peaks that result in false positive avalanche event identification. To mitigate these potential failure scenarios, location information contained in the beamforming processing is utilized as effective mitigation.

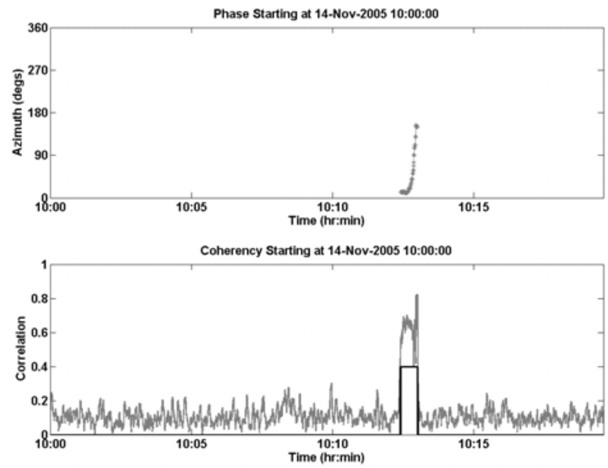

Figure 6. Twin Slides 11/14/05 Noise Nulling

Figure 6 shows improved correlation estimates for the 11/14/05 Twin Slides time period in Figure 5. The elevated baseline noise caused by wind was nulled by focusing the beamforming processing on the Twin Slides avalanche path, which allows for reliable use of a lower 0.4 correlation threshold. Enabling this performance increase is the fact that the Twin Slides sensor array is sited predominately upwind from the avalanche path.

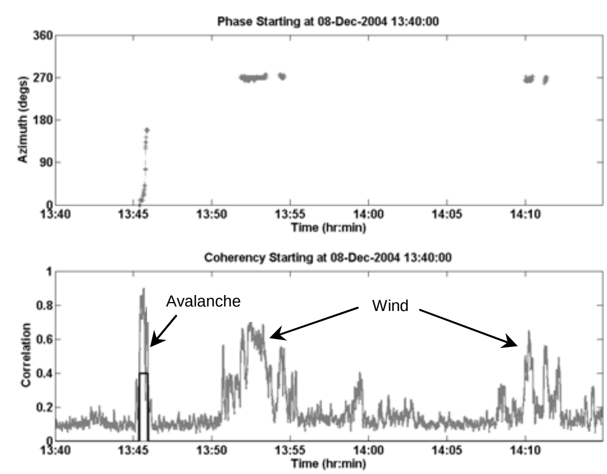

Figure 7. Twin Slides Avalanche & Wind Signals

Wind can also manifest itself in the correlation sequence as spurious peaks, which appear to be true signals. Shown in Figure 7 is a thirty minute time period in which a snowboarder triggered avalanche signal is followed by wind signals in the data recorded by the sensor array near Twin Slides. The black identification sequence denotes where the signal processing algorithm correctly identifies the avalanche event. This is true even though the wind signals also exceed the 0.4 correlation threshold value, since signal discrimination techniques are effectively used to eliminate identification of spurious peaks that exceed the threshold value.

In addition to event time duration, the signal discrimination analyses are based upon the pattern created in the azimuth angle sequence by avalanche signals traveling down a particular slide path. Such deterministic distributions of azimuth angles are exploitable to mitigate potential false positive identification of interfering infrasound signals. For the results shown in Figure 7, the movement of the avalanche across a wide range of azimuth angles enables the signal processing algorithm to eliminate the quasi-stationary wind signals from being identified.

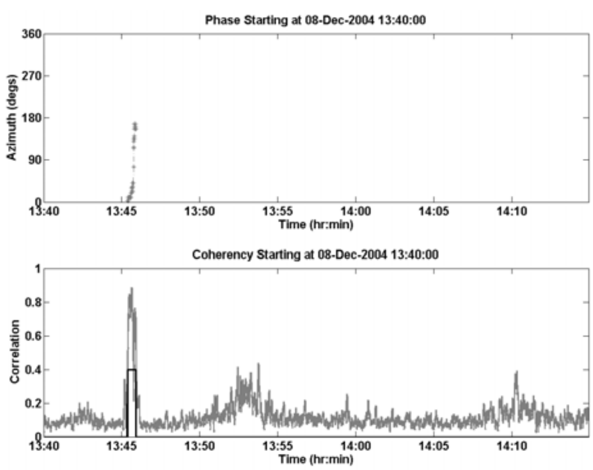

Figure 8. Twin Slides Wind Signal Nulling

For the situation depicted in Figure 7, the reliability of the signal processing algorithm can be further improved by also nulling the wind signals, which impinge upon the sensor array from a different sector than where the avalanche signals emanate. Figure 8 shows how this nulling mitigates the prevalence of the wind induced peaks in the correlation sequence.

As demonstrated in Figure 8, interfering signals impinging upon a sensor array from an azimuth angle sector not aligned with a targeted slide path can effectively be mitigated through nulling techniques and thus alleviate the need for signal discrimination. However, the signal discrimination technique of using azimuth angle movement to identify avalanche events as demonstrated in Figure 7, has to be used to mitigate any interfering signals coming from the direction of the targeted slide path. A common cause of such interfering signals are explosions emanating from the avalanche path start zone, which cannot be nulled without also nulling desired avalanche signals.

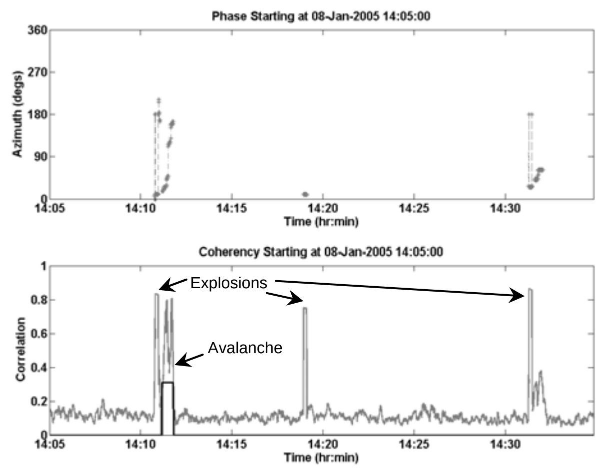

Figure 9. Twin Slides Signal Discrimination

Figure 9 shows a thirty minute time period of results obtained from the sensor array near Twin Slides in which WYDOT performed explosive avalanche hazard mitigation activities for Highway 22. The black identification sequence denotes where the signal processing algorithm correctly identifies a GazEx triggered avalanche event. Once again, the signal processing algorithm uses the azimuth angle movement of the avalanche event to successfully discriminate and eliminate the stationary explosions and associated echoes.

Even though the last of the three explosions in Figure 9 results in an avalanche event, the signal processing algorithm returns a false negative identification. This is partially due to the fact that this avalanche event does not exhibit a large range of azimuth angles and could easily be confused with interfering signals that are stationary in nature. If the signal discrimination techniques were configured to identify this avalanche event, the occurrences of false positive identifications due to interfering signals would certainly increase. Exact configuration of the identification properties must be based upon the user's desire and tolerance regarding false positives verses false negatives.

The false negative identification in Figure 9 is also due to the fact that the avalanche event occurred in the Glory Bowl slide path, which is not targeted by the Twin Slides sensor array. However, a skilled human user can quickly interpret the information and identify that this explosion resulted in a release of snow.

6. SIGNIFICANCE OF A TETON PASS MONITORING SYSTEM TO WYDOT

As has been shown, infrasound sensor array monitoring is an effective tool for detecting and identifying targeted avalanche activity. This is true regardless of the avalanche trigger (e.g. spontaneous, recreationist, or explosion). While there is obvious value in such capabilities to the avalanche professional, other uses for the technology have been found through experience gained while utilizing the technology in practical applications. Operational use of the Teton Pass infrasound monitoring system in association with WYDOT's avalanche hazard mitigation program has augmented the significance of the information offered by this technology.

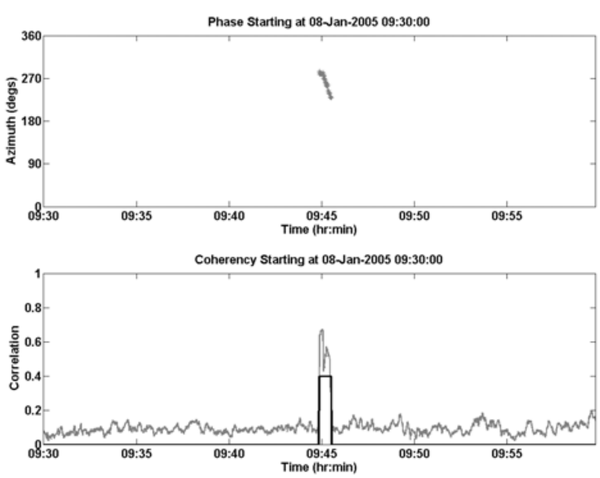

Figure 10. Spontaneous Glory Bowl Avalanche

For example, Figure 10 shows thirty minutes of results obtained from the sensor array located near Glory Bowl that contains an infrasound signal generated by a spontaneous 1/8/05 Glory Bowl avalanche event. This event occurred after WYDOT closed Highway 22 during morning commuter traffic due to a perceived avalanche hazard threatening the safety of the traveling public. Without the existence of the infrasound monitoring system, this avalanche event that did not reach Highway 22 would have gone unobserved. Since the infrasound monitoring system provided information confirming the existence of the avalanche event, WYDOT's decision to close the highway was validated. Often such decisions to close Highway 22 are scrutinized and criticized by those who rely on the highway for commercial and private use.

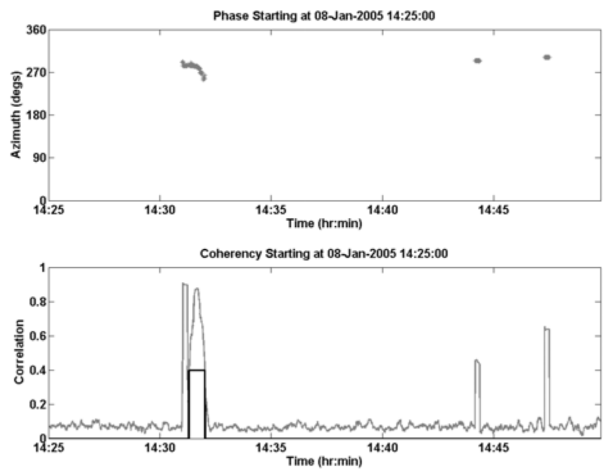

Figure 11. Subsequent Glory Bowl Snow Control

Figure 11 shows Glory Bowl sensor array results for 1/8/05 that were recorded during subsequent WYDOT avalanche hazard mitigation activities. The occurrence of an explosive triggered Glory Bowl avalanche event that did not reach Highway 22 was easily identified by the system. This is the same avalanche event that was detected by the Twin Slides sensor array after the third explosion shown in Figure 9. Again, this avalanche event would have gone unobserved without the existence of the infrasound monitoring system.

Without knowledge of the two 1/8/05 Glory Bowl avalanche events, it is easy to envision how WYDOT snow maintenance personnel might have perceived that the avalanche hazard had not been mitigated, since an avalanche event had not reached Highway 22 and thus had not been observed. However, since the infrasound monitoring system confirmed the existence of the two avalanche events, it was understood that the spontaneous event had already partially cleared the Glory Bowl start zone, which resulted in a smaller than expected avalanche triggered during avalanche hazard mitigation activities. This information confirmed that the Glory Bowl avalanche hazard had indeed been alleviated, which affected on-going operational avalanche hazard mitigation planning. As a result, an unnecessary and costly closure of Highway 22 to conduct additional avalanche hazard mitigation activities was averted.

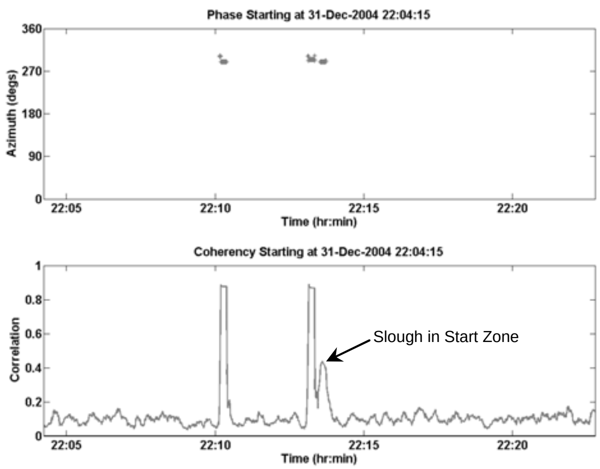

Figure 11. 12/31/04 Glory Bowl Snow Control

Shown in Figure 11 are twenty minutes of results obtained from the sensor array located near Glory Bowl during 12/31/04 WYDOT avalanche hazard mitigation activities. These activities were conducted following the spontaneous release of an avalanche event that reached Highway 22, which was shown in Figure 3. Evident in Figure 11 is the existence of a small explosive triggered slough that did not travel far from the Glory Bowl start zone. Even though the signal processing algorithm was not configured to automatically identify this avalanche event, the occurrence of the avalanche event is easily recognizable by a human interpreting the infrasound monitoring system results.

This slough would not have been observed without the aid of the Teton Pass infrasound monitoring system. Again, such results provide critical information regarding snow movement and the perceived avalanche hazard that is incorporated into the decision making of WYDOT snow maintenance personnel during operational planning.

Figure 12 shows signal processing results for a twenty-five minute period of time when WYDOT personnel used artillery to perform avalanche hazard mitigation activities near Twin Slides. Evident in Figure 12 is the launching of eight artillery rounds from an azimuth near 245°, which is from the direction of the gun mount near the top of Teton Pass. The explosion of four rounds is verified by the resulting azimuth angles near 360°/0°, which is from the direction of the avalanche path start zones. WYDOT snow maintenance personnel suspected that failed explosion of several rounds may have occurred during the control mission. The infrasound monitoring system confirmed the occurrence of these failed rounds, which WYDOT personnel attempted to locate for public safety reasons once conditions permitted.

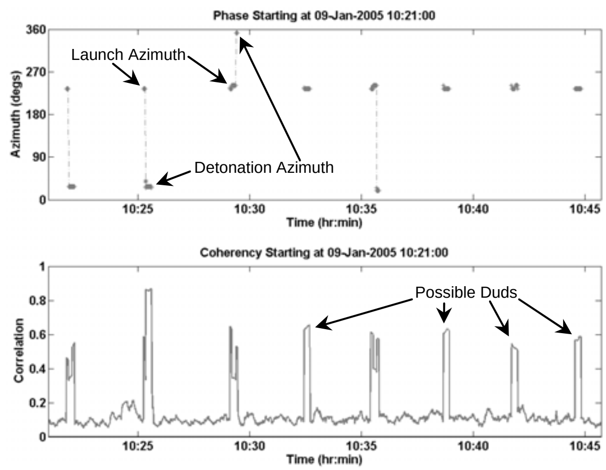

Figure 12. Unexploded Artillery Ordinance

6. PRACTICAL IMPLEMENTATION FOR WYDOT

So far, avalanche infrasound monitoring results presented in this and previous publications have largely been the outcome of research studies. Findings of the research studies hold promise for realizing a practical and fully operational monitoring system that is a valuable component of avalanche hazard mitigation programs. As a result, a prototype near real-time monitoring system has been developed and operated in conjunction with WYDOT's Teton Pass avalanche mitigation program.

Development of the prototype Teton Pass infrasound monitoring system was conducted with the goals of providing a system that is easy to use and maintain, as well as one that provides reliable continuous operation. Such automated system integration is not a trivial task and has required the custom development of both hardware and software components.

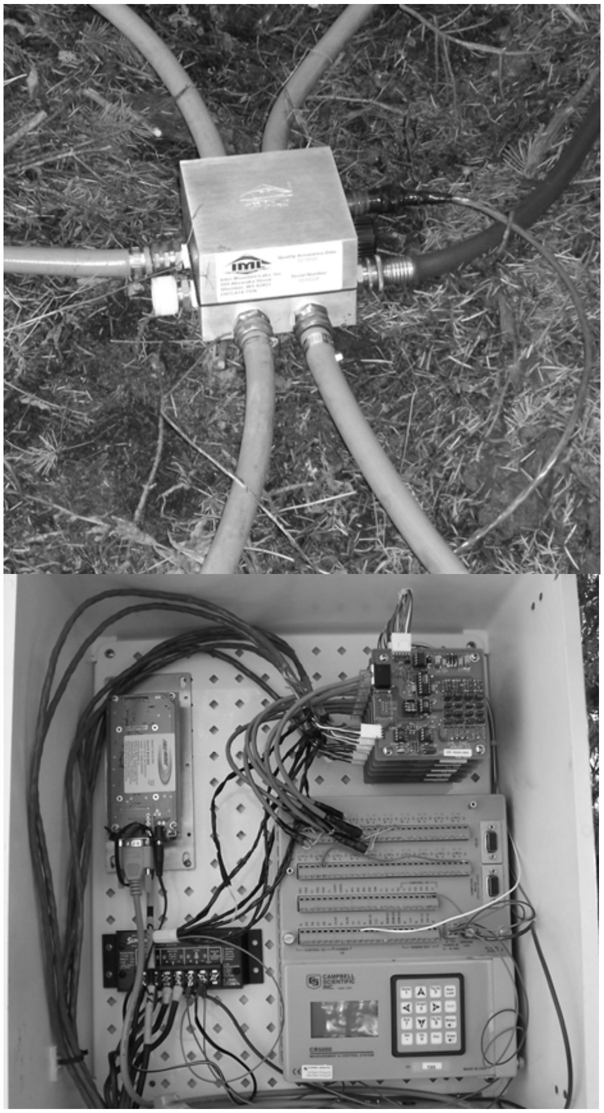

Figure 13. Teton Pass Sensor Array Hardware

Figure 13 shows examples of installed Teton Pass remote monitoring instrumentation. The top picture shows a custom prototype infrasound sensor that has provided improved wind noise performance over the commercial infrasound sensors that were used in early project research studies. The sensor is simply placed on the ground and allowed to be covered with snowfall. Snow cover is advantageous because it helps dampen wind noise. Solid and porous hoses are attached to the sensor enclosure manifold to facilitate spatially separated atmospheric sampling that mitigates detrimental effects of localized winds while emphasizing targeted infrasound signals. Acoustic energy that enters the sensor housing through the pneumatic hose apparatus is converted to electrical energy that is output on a cable for subsequent conditioning and measurement by a data acquisition system.

The bottom picture in Figure 13 shows a weather proof enclosure that houses the remaining instruments of a Teton Pass sensor array monitoring node. Sensor cables are connected to a bank of signal conditioning circuit cards in the upper right corner of the enclosure. The datalogger below the signal conditioning circuit cards measures and records the voltage levels from the signal conditioning circuit cards. Recorded data is then transmitted via the spread spectrum radio transceiver in the upper left corner of the enclosure to a central processing unit (CPU) located at the WYDOT office facility. To the left of the datalogger is a solar charging regulator that connects solar panels to a deep cycle 12 volt battery that resides on the ground

In addition to various hardware components, there are also a variety of software components that are essential to the operation of the infrasound monitoring system. Outside of programs that exist in the dataloggers at the remote sensor array nodes, other software components reside on a CPU running Microsoft Windows operating system.

Two software components facilitate operation of the infrasound monitoring system. The first is custom signal processing developed using the MATLAB technical computing language. The commercial MATLAB software package serves as a data processing engine for performing analyses and deriving results. While MATLAB is an essential component, it is largely transparent to the user and operates as a background server.

Custom stand alone graphical user interface (GUI) software, created in the Visual Basic development environment, controls the MATLAB server. Important signal processing properties and functionality have been exposed by MATLAB to the GUI, so that data processing is easily customized to meet the unique requirements of different monitoring sites. The GUI provides several interface utilities to facilitate simple access for configuring important signal processing parameters.

Another feature of the GUI is the near real-time scheduling and facilitation of data collection from the remote sensor array nodes. After subsequent data management, signal processing is performed and results are displayed by the GUI. Event logs, status logs, and alarms are automatically triggered on the scheduled near real-time interval. The GUI also facilitates the same processes to be manually driven for past time periods through user driven post processing functionality.

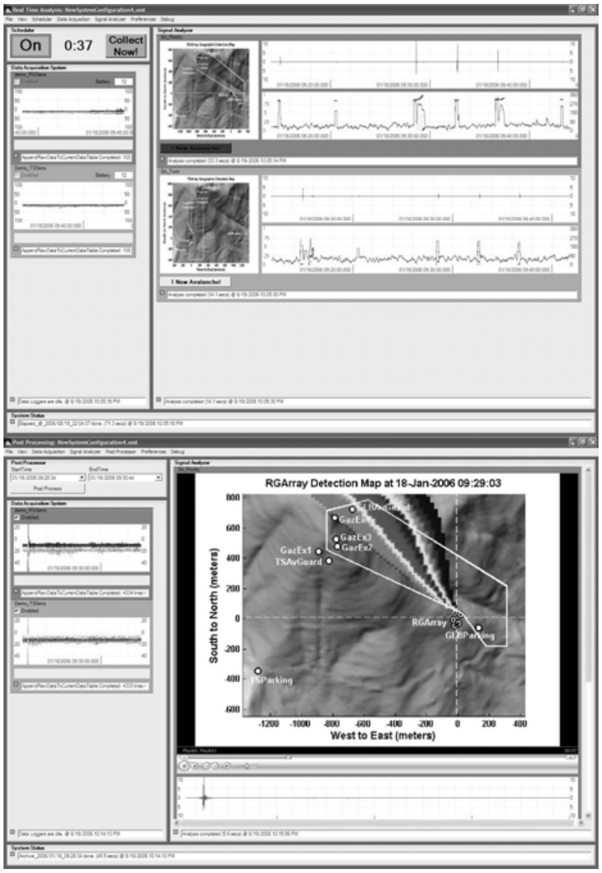

Figure 14. Teton Pass CPU Software Interface

Figure 14 shows two examples of the Teton Pass GUI. The top graphic shows how the GUI presents sensor data and the critical correlation and azimuth angle signal processing features that were obtained during a WYDOT avalanche hazard mitigation mission. In automated, near real-time operation, these graphs behave like strip charts with older results moving out as new data moves in with each data collection and processing iteration interval (e.g. 60 seconds). Identification sequences derived from signal processing results are also displayed in the strip charts. A human interpreter can quickly glean additional information from the strip chart displays regarding potential signals that have not been automatically identified as avalanche events.

The bottom graph in Figure 14 shows how a user can utilize the GUI to gain additional insight into an infrasound signal. In this example an animated sequence of geographic beamforming results is being viewed. In the case of an avalanche, the animation shows the location of the infrasound source as it moves down the slide path while the strip chart displays corresponding correlation and azimuth angle sequences. Often additional information that is not readily apparent in the strip chart sequences can be understood by viewing an animated sequence of the geographic beamforming results for a detected signal.

7. CURRENT EFFORTS

In addition to the development of a satisfactory avalanche monitoring system for use with WYDOT's avalanche hazard mitigation program, several different project details are undergoing improvement. Since the research and development portion of this project is coming to a close, most of the current efforts on this project are moving toward making the system easier to use and maintain for the users.

The first of these efforts is to provide adequate documentation and manuals for all of the system components. Documentation for the installation and maintenance of all hardware components is under development. Help and documentation for the GUI is also being created to facilitate easy operation by the user. Current efforts also include improvement of the GUI to not only make the system easier to use, but also more efficient and aesthetically pleasing.

Another important task is related to one of the main problems experienced during the 2005/2006 winter season. During these winter months the system experienced infrasonic signal degradation due to the icing and crushing of the hoses underneath the snow. Actions need to be taken to prevent this loss of signal in order to ensure the proper operation of the avalanche infrasound monitoring technology.

8. CONCLUSIONS

Throughout the course of this project, significant advances have been made in both hardware and software to develop a successful avalanche infrasound monitoring system for use by the WYDOT in conjunction with their avalanche hazard mitigation program. Custom sensors, signal conditioning electronics, and software have all been developed for use with this technology.

Advanced signal processing algorithms have been developed for an avalanche infrasound monitoring system in order to increase the reliability of such a system. These algorithms include the ability to null any interfering signals that come from a different location than the snow avalanche slide path. Also, the system has been enhanced to recognize the azimuth angle movement of an avalanche to avoid identification of any quasi-stationary interference signals that are present.

Through practical experiences gained while working with the prototype monitoring systems, several uses of this type of monitoring system have been discovered. One such use is to help WYDOT personnel monitor the use of explosives in avalanche hazard mitigation. The continuous monitoring of any snow movement, especially any activity that is hidden to WYDOT personnel, provides valuable information for evaluating the avalanche hazard level facing the public and ongoing operational planning.

The majority of work in progress on this project is moving towards making the system easier to both maintain and use. Documentation and user support is being created to make the system's software and hardware friendlier and easily maintained. A last remaining challenge to overcome is the reduced infrasound signal transmission between the atmosphere and the infrasound sensor, which was caused by the snow pack residing on the sensor pneumatic filters. Hopefully, these efforts will lead to a system that WYDOT and any other interested entity, can use with little effort to provide accurate and reliable information for avalanche hazard mitigation.

9. ACKNOWLEDGEMENTS

Efforts related to this project were funded through the following: National Science Foundation Small Business and Innovative Research Phase II award 0449731, Wyoming Department of Transportation Research Project: RS07(203).

The authors thank the following organizations and their people for providing support services that have been integral to the successes of this project; Bridger Teton National Forest, Bridger Teton Avalanche Information Center, National Science Foundation, and Wyoming Department of Transportation Research Committee.

9. REFERENCES

Bedard, A. J. Jr., "*An Evaluation of Atmospheric Infrasound for Monitoring Avalanches,*" Proceedings; 7th International Symposium on Acoustic Sensing and Associated Techniques of the Atmosphere and Oceans, Boulder, CO, 1994.

Bedard, A. J. Jr., "*Detection of Avalanches Using Atmospheric Infrasound,*" Proceedings; Western Snow Conference, Fort Collins, CO, 1989.

Bedard, A. J. Jr., G. E. Greene, J. Intrieri and R. Rodriguez, "*On the Feasibility and Value of Detecting and Characterizing Avalanches Remotely by Monitoring Radiated Sub-Audible Atmospheric Sound at Long Distances,*" Proceedings; A Multidisciplinary Approach to Snow Engineering, Santa Barbara, CA, 1988.

Chritin, V., M. Rossi, and R. Bolongensi, "*Acoustic Detection System for Operational Avalanche Forecasting,*" Proceedings; International Snow Science Workshop, Banff, Alberta, 1996.

Comey, R. H. and T. Mendenhall, "*Recent Studies Using Infrasound Sensors to Remotely Monitor Avalanche Activity,*" Proceedings; International Snow Science Workshop, Jackson, WY, 2004.

Scott, E. D., et. al., "Single and Multiple Sensor Identification of Avalanche-Generated Infrasound", *Cold Regions of Science and Technology*, Special ISSW 2004 Addition, accepted 2006.

Scott, E. D., 2005, "*Infrasonic Monitoring of Avalanche Activity on Teton Pass*", Final Report FHWA-WY-05/08F by Inter-Mountain Laboratories, Inc. submitted to the Wyoming Department of Transportation and the Federal Highway Administration, Pursuant to WYDOT research project RS07(203).

Scott, E. D., et. al., "*Results of Recent Infrasound Avalanche Monitoring Studies*," Proceedings; International Snow Science Workshop, Jackson Hole, Wyoming, September 2004.

Scott, E. D., and C. Lance, "*Infrasonic Monitoring of Avalanche Activity,*" Proceedings; International Snow Science Workshop, Penticton, British Columbia, 2002.