Avalanche Rescue using Ground Penetrating Radar

Justin J. Modroo and Gary R. Olhoeft
Department of Geophysics
Colorado School of Mines
Golden, CO USA
jmodroo@mines.edu, golhoeft@mines.edu

Abstract

Every year world-wide, over 150 people are killed by snow avalanches. Method of rescue statistics show survival is best when skiing with a companion (69% survival) and having something stick out of the snow after burial like an avalanche cord or ski (72%) followed by use of personal radio transceivers (40%). Organized searches (16% survival) using probe lines (12%) and search dogs (11%) take time to assemble. Victims only have a 30% chance of survival after the first hour of burial, and only 35% if buried deeper than 1 meter. Ground penetrating radar (GPR) could provide an efficient method for locating buried avalanche victims. Snow is an excellent propagation media for GPR waves. A human body is highly conductive with a high dielectric permittivity contrast relative to snow, serving as an ideal reflector target for GPR. However, it has been unknown how GPR will respond to the unfavorably changing dielectric properties as a body freezes. It is also unknown whether or not GPR can distinguish a human body from other natural and man made objects in the avalanche debris field. A human body mass equivalent (BME) was buried in snow, and the GPR response and core temperature were recorded versus time as the BME froze in a simulated avalanche burial at a cooperating ski area. A freshly euthanized pig was used as the BME, due to the similarity in properties to that of a human body. The experimental measurements show that it takes about 110 hours for the 145 pound BME to completely freeze while buried in snow with an ambient temperature of -7 °C. Throughout the course of the experiment, the BME could be uniquely identified relative to other buried natural and man made objects by its imaging GPR signature. Modeling showed this was a consequence of a unique phase shift from constructive and destructive interference occurring in a thin layer sequence at the BME-air-snow interface. This resulted from initial body heat melting of snow, development of a thin air pocket, and subsequent refreezing. Thus, GPR has the potential to image, identify and locate a human body and therefore possibly save lives, or at a minimum, help recover the body before spring thaw.

Keywords - ground penetrating radar, avalanche rescue, snow.

Introduction

Avalanche activity is a normal process of winter in the mountains. Avalanche deaths world-wide have been on the increase since the early 1990's. Based on recent yearly averages, the United States has 30 avalanche fatalities, while there are 150 avalanche fatalities world-wide. In order to help save the buried victim, the first 30 minutes are the most crucial, after which the chance of survival drops below 50% (all statistics are from Atkins [4]). Though rare, there have been successful rescues of avalanche victims that have been buried for over 12 hours.

Currently, the best way to locate an avalanche victim buried with nothing sticking out of the snow is by a skiing companion using a special radio transceiver (avalanche beacon) [13]. Each individual's transmitter constantly transmits at 457 KHz, and after one is buried, the surviving companion switches their transceiver to receive in order to locate the buried person (40% survival). However, a majority of avalanche victims are not wearing transceivers, or it is lost or broken as the victim is buried. Another rescue method is the RECCO Rescue System [11], popular in Europe. Victims are equipped with special reflectors, which double the frequency of the transmitted rescue signal to help pinpoint the victim. If the victim does not have the requisite equipment (or it is separated during the avalanche), the search and rescue team is limited to only two options, both of which can be flawed.

The first, and faster, option is the use of a specially trained rescue dog to sense the buried victim. However, the victims scent can become contaminated if the area is searched by party members or rescuers prior to the dog's arrival [11]. Another problem is rapid air movement, created from wind or an active helicopter, which will dilute and disperse the victim's scent. If the victim is completely entombed in snow, allowing no air flow to the surface, the dog's nose is rendered useless. The final method is the slow and methodical use of a probe line. This consists of a line of 3 to 20 people, equipped with 2 to 3 meter probe poles, systematically probing the debris field together [11]. These methods consume too much valuable time in organizing the rescue, so survival drops to 16% or less [4]. No search method works all the time, not even in combination. Due to the inadequacies of the current rescue methods, sometimes bodies are not recovered until the summer thaw. A more efficient and reliable method is needed to help save lives and recover bodies.

A Possible Solution

It should be possible to efficiently and effectively image a human body buried in snow utilizing ground penetrating radar (GPR) [7, 12]. Snow and ice provide an excellent propagation media for electromagnetic (EM) waves [1, 2, 9, 10]. The human body, a highly conductive mostly liquid medium [5, 6], serves as a high electrical contrast reflector for GPR EM waves in snow, and is thus an ideal GPR target.

The propagation and scattering of EM waves are controlled by geometry and three physical properties of the host medium: dielectric permittivity, magnetic permeability, and conductivity. The magnetic permeability of relevant materials is that of free space. Dielectric permittivity is the ability of a material to maintain charge separation and store energy. The product of dielectric permittivity and magnetic permeability controls the wavelength and velocity of the EM wave propagation. Conductivity represents energy loss by transfer to heat and attenuates the propagation of the EM wave, limiting depth of investigation. When a wave encounters a change in one or more of these properties, some energy is scattered, creating a reflection.

The relative dielectric permittivity of snow varies from 1.2 to 12.0 depending on several factors, including the amount of moisture content, density, grain size and shape, temperature, and frequency [1, 10]. The average human body permittivity of 50 was determined using a weighted average of the 5 main components of the human body: skin, bone, blood, organs, and fat [5, 6]. The permittivity of the range of other materials that might be present in avalanche debris (rocks, trees, boots, etc.) ranges from 2 to 12.

Using the criteria that the size of the EM wavelength in snow needs to be no more than 3 times the size of the target, commonly available 450 MHz and 900 MHz GPR frequencies should both be capable of detecting a body, regardless of its orientation. To help understand if GPR could be used as an effective rescue imaging system the following fundamental questions need to be answered. How will GPR respond to a freezing body? How long will it take for a body to freeze while buried in snow? Will it be possible to distinguish a body from other anomalies?

Simulation Experiment

To help answer these questions, an experiment was designed to simulate the environment of an avalanche victim. A human body mass equivalent (BME) was buried in snow to simulate the buried victim. The BME's core temperature and GPR response were measured over time, and a database of GPR responses to natural and man-made objects was acquired.

In order to simulate the human body, the BME needed similar electrical and thermal properties. Pigs have been used for xenotransplantation of organs into humans [3, 15] because they have similar physiological properties to the human body. A common Yorkshire cross swine was used in this experiment. The Yorkshire family is Suidae, the genus is Sus, and is known as the Sus Scofa species. Colorado State University's regulations were followed regarding animal research in the absence of any at the Colorado School of Mines. In accordance with the Animal Care and Use Committee (ACUC), a pig destined for slaughter was intercepted between auction and butcher. A veterinarian then euthanized the pig, at which point, the experiment began by burial of the pig in snow. The BME weighed approximately 145 pounds, was 1 meter long and 60 centimeters tall.

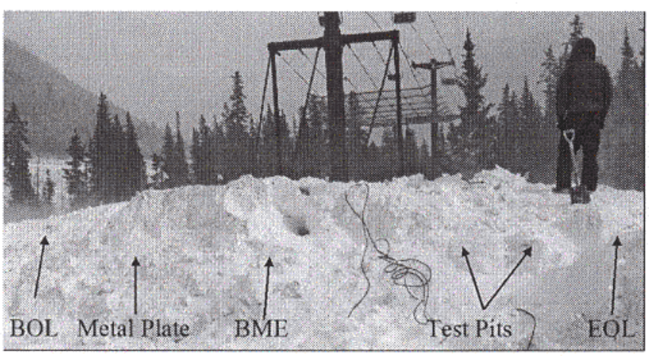

Figure 1. Experiment survey lines

To measure the core temperature of the BME, a specially designed thermometer pill (CorTemp technology HQ Inc. Palmetto, FL) was made for the BME to swallow prior to euthanization. The pill contains an oscillating crystal sensitive to temperature. The pill transmits the crystal's signal to a nearby receiving unit operating at 252 KHz.

Loveland Ski Area (CO, USA) cooperated by providing a location for the test, where they consolidated snow from plowing their parking lot. The experiment took place from 21-25 November 2003.

The BME was buried in the deepest part of the snow pile. There was 0.9 meter (3 feet) of snow under the BME and roughly 0.76 meter (2.5 feet) above it. The BME was placed on its side with the GPR traverse orientated along the long axis of the body. Once buried, a test line was created directly above the BME. Fig. 1 shows a photo of the survey line. The beginning of line (BOL) and end of line (EOL) are annotated along with the corresponding target burial locations.

The test line consisted of flags every three feet to help keep the survey geometry known. A metal plate was buried near the beginning of the line (BOL) for calibration purposes. Test pits were located at the end of the line where natural and man-made objects were to be buried. A Pulse-Ekko 1000 GPR unit was used to acquire the data using two different ground coupled antennas: 900 MHz and 450 MHz. A track the width of the GPR antennas was made to ensure that the same line was mapped with each repetition. Most GPR measurements were collected using the 900 MHz antenna, and the 450 MHz antenna was used less frequently as a compliment. The first measurements were gathered at 110 minutes (900 MHz) and 121 minutes (450 MHz) after burial. For the first 16 hours, a GPR measurement was made every half hour. The GPR measurement rate was then changed to one every hour. Problems did arise and staying consistent on the hour proved almost impossible due to blown fuses, cold and damp equipment (during a blizzard), and cold batteries (at night).

Several additional natural and man made objects were buried for comparison with the BME response, including: metal plate, ski coat, rocks, dirt clods, pine bows, ski boot, shovel, ski helmet, backpack, ski pole, ski, freshly cut tree shrub, and log. Most of these targets were oriented to achieve maximum coupling to the GPR antenna polarization.

Results

Four temperature measurements were recorded during the experiment: the BME's core, the air, the surface snow, and ambient snow. The CorTemp thermometer pill worked well, providing a large amount of data. The BME's core temperature started out at approximately 38° C (close to the human normal 37° C), declining over 110 hours to 0° C freezing, with the ambient snow temperature at constant -7° C.

BME's amplitude peaked at approximately 10 hours after burial and then exponentially decayed, with a 30% decrease at the final measurement made 96 hours after burial.

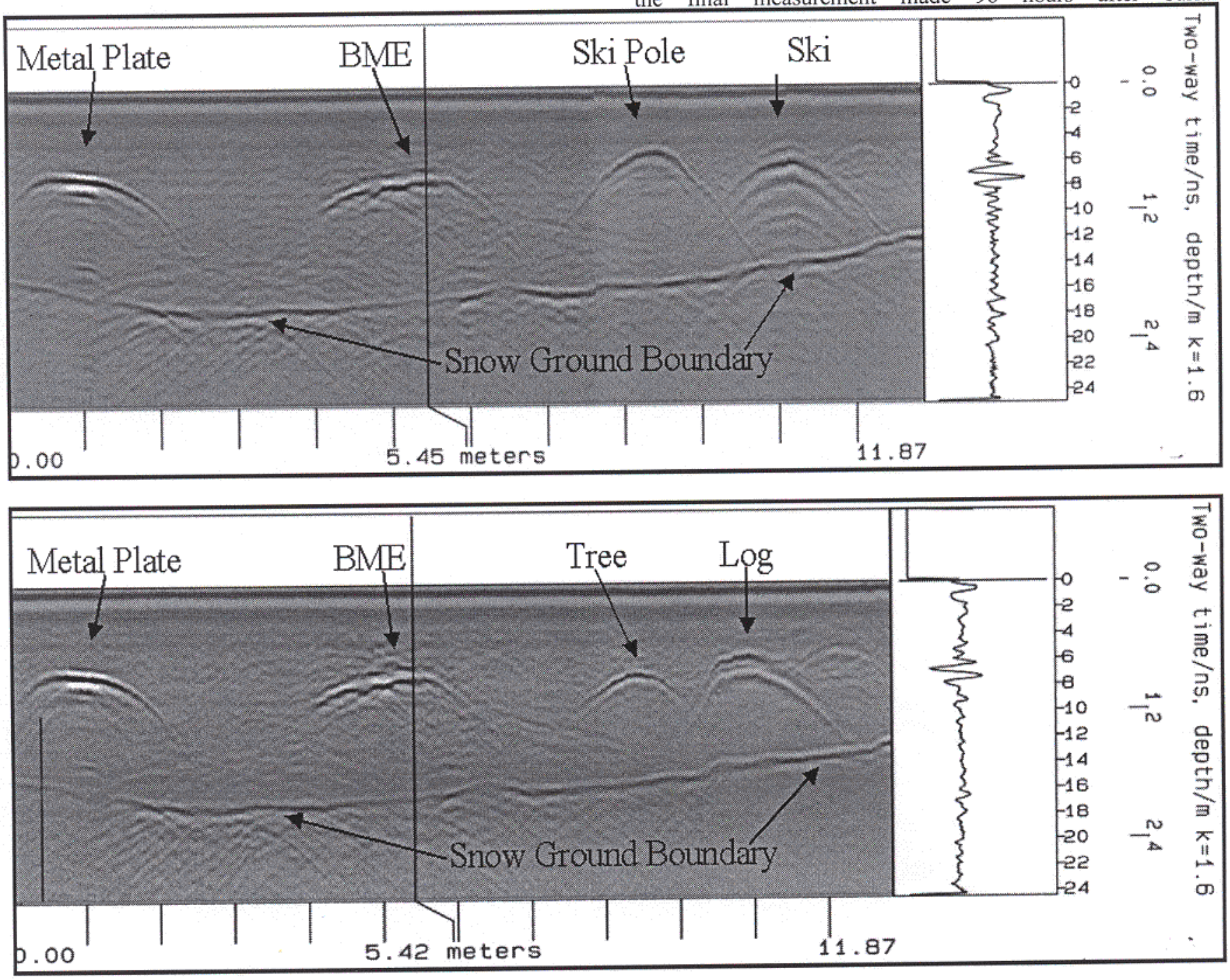

Figure 2. Example 900 MHz radar cross-sections at 46 (top) and 94 hours.

The example GPR cross-sections in Figure 2 were minimally processed: the zero time was set, a rubber sheet geometry correction was applied, and the data were range gained. Approximately 50 different GPR measurements were collected using the 900 MHz antenna versus time. In Figure 2, the top radar image shows the BME plus a ski and pole at 46 hours after burial with the BME core temperature at 8° C. The bottom image shows data collected at 94 hours after burial with a buried tree and a log and the BME core temperature at 1° C. Notice that the BME was still easily recognizable, and had sufficient contrast with snow to provide an identifiable reflection throughout the entire experiment.

Notice that the actual shape of the BME's wavelet is completely different from all other targets. All the other targets have a "typical" wavelet; while the BME's is phase reversed and "unique". After analyzing the same trace over time, the The early rise in amplitude is representative of the formation of an air pocket. The later decay in amplitude can be attributed to the actual freezing of the BME.

To gain a better understanding of how each target responded and why the BME wavelet was unique, full waveform modeling was performed. Using GRORADAR software [8], traces directly over the targets were selected for further analysis. Figure 3 shows the reflected wavelets of several natural and man-made objects expected to be found in avalanche debris fields, relative to the earliest 900 MHz BME measurement. Here, we see that the experiment agrees with theory. The BME and man-made objects provide significantly larger reflection amplitudes than the natural objects. This proves that GPR can discriminate the difference between natural and objects of interest for locating an avalanche victim.

MODELING

Figure 4 shows the modeled response for five different scenarios. The first left to right, shows the response from two layers, snow and a human body. The final four

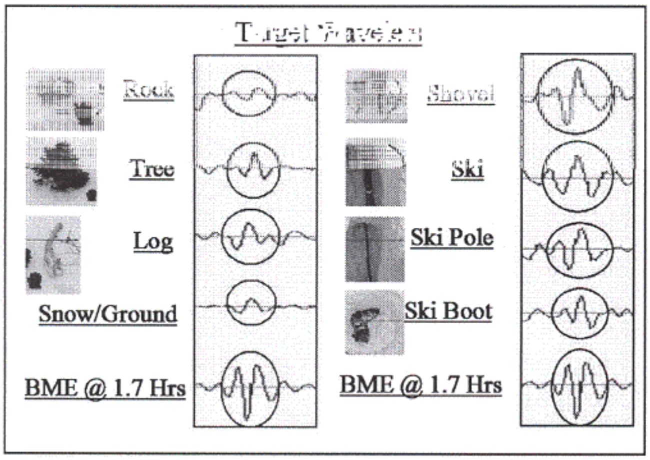

Figure 3. Comparison of natural and man-made target 900 MHz reflections relative to the earliest BME reflection.

models have three new layers that are located between the snow and human body. The layered model is: snow, ice, air, frozen skin, and an unfrozen human body.

The final four models vary only with the thickness of the three new layers. Each layer was given a 1cm increment. So, in the final model each new layer has a thickness of 4 cm. In this case, the thin layers provided constructive and destructive interference that completely changes the shape of the wavelet. The final model is a similar match to the shape of the BME's reflected wavelet. This model did agree with both the 900 MHz and 450 MHz data, in which a 4 cm air pocket had developed after 2 hours of burial.

CONCLUSION

The experiment provided much new information, including the following four main points. First, the 145 pound BME completely freezes while buried in snow with an ambient temperature of -7° C in 110 hours. Second, GPR can effectively locate the BME regardless of core temperature. Third, GPR can uniquely identify the BME and man-made objects from natural objects at any time, based on relative amplitude comparison. Finally, the 900 MHz antenna is able to uniquely identify a body once a 2 cm air pocket and associated ice layers have developed giving a unique wavelet reflection.

Air pockets develop when an avalanche victim loses heat, melting snow. All avalanche victims that have been recovered have developed air pockets [4]. The size of the air pocket ranges from millimeters up to 8 centimeters. This depends mainly on how well insulated the victim is. However, the area around the face of a victim usually has the largest gap due to breathing and lack of insulation.

A GPR system, aided by the use of a helicopter, could help save lives. The helicopter could be used to deploy rescuers equipped with a portable GPR unit, or for the actual mapping of the debris field and deployment of rescuers.

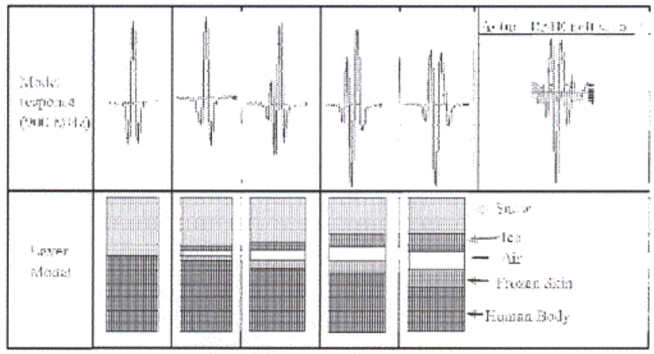

Figure 4. Modeled layer response for 900 MHz wavelet.
* Wavelet trace was selected from 900 MHz data colected 8 hours after burial.

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