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Using Geographic Information Systems for Avalanche Work

By Chris McCollister and Karl Birkeland

Recently there have been an increasing number of calls from snow folks, Geographic Information System (GIS) specialists, and the public to more fully utilize GIS for snow avalanche work. And why not? Avalanche work relies on terrain, and a key component of many uses of GIS includes detailed terrain models that can be manipulated in a variety of ways. Further, GIS is a great way to create colorful, detailed maps that can help the public better understand many complex processes. The purpose of this short paper is to discuss whether or not GIS is currently appropriate for some of the uses for which it has been commonly suggested. Further, we will briefly discuss some of the ways that GIS is currently being used in our field.

Folks commonly suggest two primary uses for GIS. The first is that GIS can be used to effectively map avalanche terrain. This typically involves mapping starting zones by looking at slope angles and vegetation cover. More complicated models use various techniques to move the snow from the starting zone downhill, thereby mapping out avalanche tracks and runouts. The second common suggestion for GIS is to use it for avalanche forecasting. Some propose the creation of a complicated model that attempts to map factors like snowfall, wind loading, energy balance, and changes in weak layer strength through space to come up with a detailed map of potential problem areas in the snowpack. More commonly, and on a much more basic level, people suggest using a GIS to visually display the avalanche danger currently being forecasted by a local avalanche center onto the terrain of interest.

This paper covers three main topics. First, we discuss GIS in terms of how accurately current technology can represent reality on the ground. Second, we utilize data from Jackson Hole Mountain Resort to investigate how well a GIS can map starting zones and runout zones within the ski area. Finally, we discuss the role of GIS in avalanche forecasting models and in displaying avalanche forecasting products. In our opinion, there are clearly many appropriate uses of GIS in avalanche work, and we discuss some of these at the end of this paper. On the other hand, sizable limitations exist that must be recognized and addressed for avalanche-related GIS work.

How well does GIS reflect reality?

The first thing that folks need to keep in mind when they are using a GIS is that they are looking at a depiction of reality. We tend to get excited about the graphics and colors dancing around on the computer screen in front of us and lose track of how that really reflects what is found on the ground.

The two most important data layers for looking at avalanches with a GIS are a vegetation layer and a digital elevation model (DEM). The vegetation layer gives an idea about the number of trees on a slope, which can provide insight into the anchoring of a particular slope. Ideally, these will be accurate data, though the user must be aware of when they were collected. If these data are old, subsequent logging or fires may have decreased forest density in some areas, or density may have increased through time as trees grew.

Probably a greater concern in terms of its reflection of reality is the DEM. Remember that the "M" in DEM stands for model, so the DEM is simply a model of reality. The resolution of a DEM reflects its detail. Thirty meter DEMs, which are widely available throughout the U.S., have points on a 30 by 30 m grid, meaning that intermediate points must be interpolated between those points. Ten meter DEMs are available in some areas, and still other place may have finer DEMs available. The terrain model we use for Jackson Hole is based on work by planning engineers and is a 3 m DEM. As you will see, even with a 3 m DEM there can be large discrepancies between what the DEM depicts and what we see on the ground.

The resolution of the DEM means that in some cases small avalanche slopes can be completely missed. For example, when using a 30 m DEM, a person would probably use a minimum of three points to calculate the slope angle, and most likely 5 or 9. This would mean that the two outer points would, at a minimum, be 60 m (or about 200 ft) apart. If other calculation schemes with larger numbers of points are used, the problem of missing small terrain features may become further magnified.

The basis for the DEM is the elevation for each data point. The absolute accuracy of these elevation points is about 3 m for a 30 meter DEM. So, we can see that the DEM will give us a fairly accurate measure of elevation, typically within about 10 feet of the actual value. The accuracy of other values will vary depending on the calculations involved and just how accurate a depiction is needed. For example, if we feel it is acceptable to break down aspect into 8 different directions (N, NW, W, etc.) we can do a reasonably good job because each category is comprised of 45-degree bins. On the other hand, we may not find it so easy to differentiate between a slope with an aspect of 95 degrees with one that has an aspect of 100 degrees. Still, for most avalanche work, aspect calculations are probably sufficient.

A primary concern with depicting avalanche terrain with a DEM is the accuracy of slope angle calculations. Slope angle is arguably the most important attribute for assessing avalanche terrain, but is relatively poorly represented by DEMs at the accuracy demanded by avalanche work. We all know that subtle changes in slope angle can mean big changes in avalanche frequency, so knowing the difference between a 28 degree slope (which almost never slides), a 33 degree slope (which sometimes slides), and a 38 degree slope (which commonly slides) is critical, and these changes are much too subtle to be picked up with a DEM. Even if we look more generally at slope angles, like at angles from 30 to 45 degrees, generating slope angles accurate enough for avalanche work is challenging. This does not mean that avalanche work with a DEM is impossible – it simply means that the user must recognize these limitations.

Using GIS for mapping avalanche terrain

One of the most common suggestions for utilizing GIS in avalanche work is to map avalanche terrain. At first glance, mapping avalanche terrain seems to be a no-brainer. At the least, areas with calculated slope angles from 30 degrees to 45 degrees ought to give us a start for identifying avalanche starting zones. To test the effectiveness of a GIS in identifying avalanche terrain, we utilize data from Jackson Hole Mountain Resort that has been used in previous research (McCollister and others, 2003; McCollister, 2004).

First we created a layer of possible avalanche areas based entirely on slope angles between 30 and 45 degrees. We then compared that map to a map of known starting zones created when snow safety director Bob Comey digitized the avalanche paths in consultation with other senior snow safety personnel at the ski area (Figure 1). In general, the technique did OK, correctly identifying about 75% of the avalanche starting zones. However, about 25% of the area of avalanche starting zones was missed. In addition, there was an enormous amount of areas where the GIS identified avalanche starting zones even though none existed. In fact, these "false positive" areas outnumbered the correctly identified areas by a ratio of over 10 to 1. One reason for the high "false positive" ratio could be that we didn't use vegetation data in our simple mapping procedure.

Next, using the same layer that identified avalanche areas based only on slope we compared those areas to a map of approximate runout zone for size 5 avalanches created by Bob Comey and his crew. The GIS correctly identified runout zones only about 45% of the time, while they were missed 55% of the time. The bottom line here is that there were more misses than hits, so slope clearly did not adequately characterize the avalanche runout zones in the area. More refined techniques can be used to map runout zones with a GIS, but given the difficulties with mapping even individual runout zones using standard techniques such as air photos, statistical models, and dynamics models, it is clear that misclassification rates will remain relatively high.

Given the misclassification rates, how useful is GIS for mapping avalanche terrain? Clearly, more sophisticated mapping techniques can be used, and these can reduce misclassification error. For example, detailed work by Furdada and others (1995) mapping avalanche terrain with a GIS in the Pyrenees resulted in a misclassification rate of about 15%. Still, misclassifying more than 1 in 10 areas is probably unacceptable for many applications. Although the GIS may be able to give a person a reasonable first guess as to the avalanche terrain in a specific area, each map will have to be carefully field verified by an expert before that map can be used or released to the public. Given the data and techniques currently available, mapping avalanche terrain with a GIS over large areas accurately enough for anything more than general planning purposes is not possible. However, as higher resolution DEMs and more sophisticated vegetation data become available, we will likely see improvements in GIS avalanche mapping capabilities.

Using GIS for avalanche forecasting models and for displaying avalanche forecasting products

One especially common suggestion is to use GIS for a sophisticated avalanche forecasting model that would use the existing snowpack, recent weather, and terrain to determine avalanche potential over broad areas. On the surface, it seems like a great idea. However, on closer inspection there are many problems. Campbell and others (2004, and reprinted in this issue of TAR) discussed in detail why such mapping over individual slopes is currently not feasible. In essence, we simply cannot model the many factors that go into assessing stability at the necessary scales. It addition to the problems with relatively simple factors like calculating slope angles, we have additional difficulties such as modeling new snow and wind loading over space and time. Once those difficulties are overcome, we still need to be able to map the snowpack in detail over particular slopes. Those who remain unconvinced need only to go to the large body of spatial variability research to see the problems in such an approach (for a start, you can check out a number of papers and theses on the subject at the web pages for the Forest Service National Avalanche Center (http://www.fsavalanche.org/NAC/techPages/techPap.html) and the University of Calgary Applied Snow and Avalanche Research Group (http://www.schulich.ucalgary.ca/Civil/Avalanche/papers.htm)). Even with increasingly sophisticated tools and intensive data collection efforts, investigators are finding it difficult to explain, let alone predict, the patterns of shear strength or stability test results on individual slopes.

If such complicated models are not feasible, then perhaps we can simply take the forecasted avalanche danger rating and use GIS as an effective way to present that information to the public. This has probably been the most common suggested use for GIS from the public. Since many avalanche centers currently provide avalanche danger by aspect and elevation, and some centers provide avalanche danger roses, transferring the avalanche danger over to a terrain map would not be difficult. Further, as we discussed earlier, the GIS can do a reasonably good job with aspect and elevation.

Putting avalanche danger on a map is not without its problems, however. First of all, we have already seen how difficult it is to map avalanche starting and runout zones using a GIS. If we would like to create a map that is going to shade only avalanche terrain, we will find it impossible to accurately map all the avalanche terrain over the broad areas covered by backcountry avalanche centers without detailed field surveys that could potentially take years of effort. A second approach would be to include all areas of a given aspect and elevation in the map, regardless of whether or not they are avalanche terrain. The problem this creates is that now our map will specify an avalanche danger for some areas that, because of the terrain, may not have any avalanche danger at all, regardless of the conditions.

A second problem with putting avalanche danger ratings from an avalanche center onto maps is that we all know there are exceptions in the field that cannot be taken into account on a map. For example, south of Jackson Hole Mountain Resort there are several large slopes with similar aspects and elevations. If the Bridger-Teton Avalanche Center used a GIS to display avalanche danger by aspect and elevation, these slopes would have the same avalanche danger applied to them (Figure 3). However, while No Name and the Powder 8 Faces avalanche relatively frequently, the wind patterns in the range scour the face of Rendezvous Peak, so this area usually has no avalanche danger. We're sure everyone can think of many such exceptions in their area where a particular slope with a similar aspect and elevation to adjacent slopes is typically much more unstable (or stable) than its neighbors. Any map released to the public must be corrected for these many exceptions or the public could misinterpret the map as showing a particular location to be more or less dangerous than it is in reality. The bottom line is that an avalanche danger rose or the discussion section of an avalanche advisory conveys a certain amount of uncertainty, which is appropriate given the problems we face when putting out avalanche information to the public. On the other hand, putting such information on a map suggests an unrealistic level of certainty that can be easily misinterpreted by the public.

What *should* we use GIS for in avalanche work?

Thus far, our discussion has focused on primarily on the limitation of using GIS in some of the more commonly suggested applications. However, there are many appropriate ways that GIS can be and is being used in avalanche work. One excellent use of GIS is to allow professionals to better display and interpret our ever-increasing volumes of data. We will mention just a few examples. At Switzerland's SLF, the avalanche warning team benefits from the services of GIS specialists who manage incoming data such as snowfall and wind speed and direction from numerous remote stations, and map those data over Switzerland so it can be more effectively analyzed. Up at Canadian Mountain Holidays heli-ski operations, Pascal Hägeli has helped to set up some GIS products currently used operationally by the guides. CMH now has a daily map of their area that displays the avalanche activity, stability assessment, and the drainages skied for each of their many operations. In addition, each operation has a daily run map for planning the day's skiing. CMH clearly recognizes the potential application of GIS for the many facets of their operation as evidenced by their hiring of a full-time GIS technician this season.

Like CMH, Jackson Hole Mountain Resort is investing in GIS for their avalanche work. Recently the snow safety crew at the area mapped the extent of avalanches for five different class sizes for each of the 250+ slide paths inside the ski area boundaries. Using these data, a customized computer program now automatically creates a map depicting historic avalanche activity for any given period of time (Figure 5). This allows avalanche hazard reduction crews to view events that occurred on previous days, throughout the season, or even over several years. Additionally, start zone information such as the average aspect and elevation is also calculated for the avalanche events. GIS data can also be used in conjunction with other database methods, such as Nearest Neighbors. GeoWAX, a program developed by Chris for his MSc degree at Montana State University, effectively links their historical weather and avalanche data with the previously mentioned map of avalanche terrain within the ski area. Using this system, forecasters can quickly create maps representing the historical avalanche activity on days with conditions similar to the current day or see how changes in a given parameter (such as wind direction) affect the pattern, type, and size of avalanches in the area (Figure 6) (McCollister and others, 2003; McCollister, 2004).

In addition to use by professionals, GIS can be used appropriately to better display information for the public. For example, Parks Canada recently took air photos to create 3D terrain models with a GIS. They then manually mapped avalanche terrain onto these models and are displaying it on trailheads and on the web (see http://www.pc.gc.ca/pn-np/ab/banff/visit/visit7a9_E.asp for some of their maps). This approach can give the public a clearer view of the avalanche terrain in the area they are traveling.

Numerous other possible applications exist. For example, the Bridger-Teton Avalanche Center has three forecast regions. Chris used GIS to analyze the percentage of the different regions that have steep slopes, and also the percentage of the regions with varying aspects. Such an analysis allows forecasters to better understand some of the differences between various forecast regions. Another possible use for GIS is mapping where avalanche events occurred. Forecasters or the public could enter avalanche observations using a GIS format to get the exact location of a slide. Then standard GIS query tools can be used to modify the map for specific time periods, avalanche size, aspect, elevation, slope, or any other information about the slide path (depth, failure layer, people caught, etc). The bottom line is that the number of applications is limited only by our imaginations and our abilities to manipulate the GIS.

Summary

Used correctly, GIS can be a useful and powerful tool for avalanche work. It can be used to effectively display and interpret the increasing volumes of data available to avalanche forecasters. However, as avalanche professionals we must also recognize its limitations. Creating maps of avalanche terrain over broad stretches of terrain is an inviting prospect, but we must ask if the planned use of such maps can tolerate the known misclassification in those maps, or if sufficient resources are available for adequate field verification of the maps. Likewise, mapping avalanche danger on digital elevation models creates a visually exciting, colorful way to show avalanche danger over an area. However, if such a representation lacks accuracy, is it useful for the public, or is it actually a misrepresentation of our knowledge of the current situation?

One thing we can be sure of is that GIS technology will continue to improve. Digital elevation models will get better, as will remote sensing techniques for identifying vegetation. As a group we should continue to monitor the progress of GIS technology; in the future we may well be able to create products such as useful avalanche terrain maps. In the meantime, there are many practical applications of GIS in the avalanche field that can be used to improve our operations.

Acknowledgments

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Like many avalanche folks, Chris McCollister manages several jobs to stay afloat. In addition to working as an avalanche forecaster for the Bridger-Teton National Forest Avalanche Center, he works part time for the Jackson Hole Ski Patrol and does software development for other avalanche related projects (like the infrasonic avalanche detection system currently in development). His Masters Degree in Geography from Montana State University focused on developing techniques for integrating GIS and historical avalanche and weather data, and he worked as a teaching assistant for GIS courses while going to school.

Karl Birkeland worked as a ski patroller and an avalanche forecaster – and spent too many years as a graduate student – before he landed in his current position as the Avalanche Scientist for the Forest Service National Avalanche Center, where he is responsible for transferring new and emerging technology to the regional avalanche centers. He's messed around a little with GIS, but commonly finds himself calling Chris with any GIS questions that come up. When he's not working he enjoys chasing his two young daughters around Bridger Bowl, an activity that is becoming increasingly challenging.

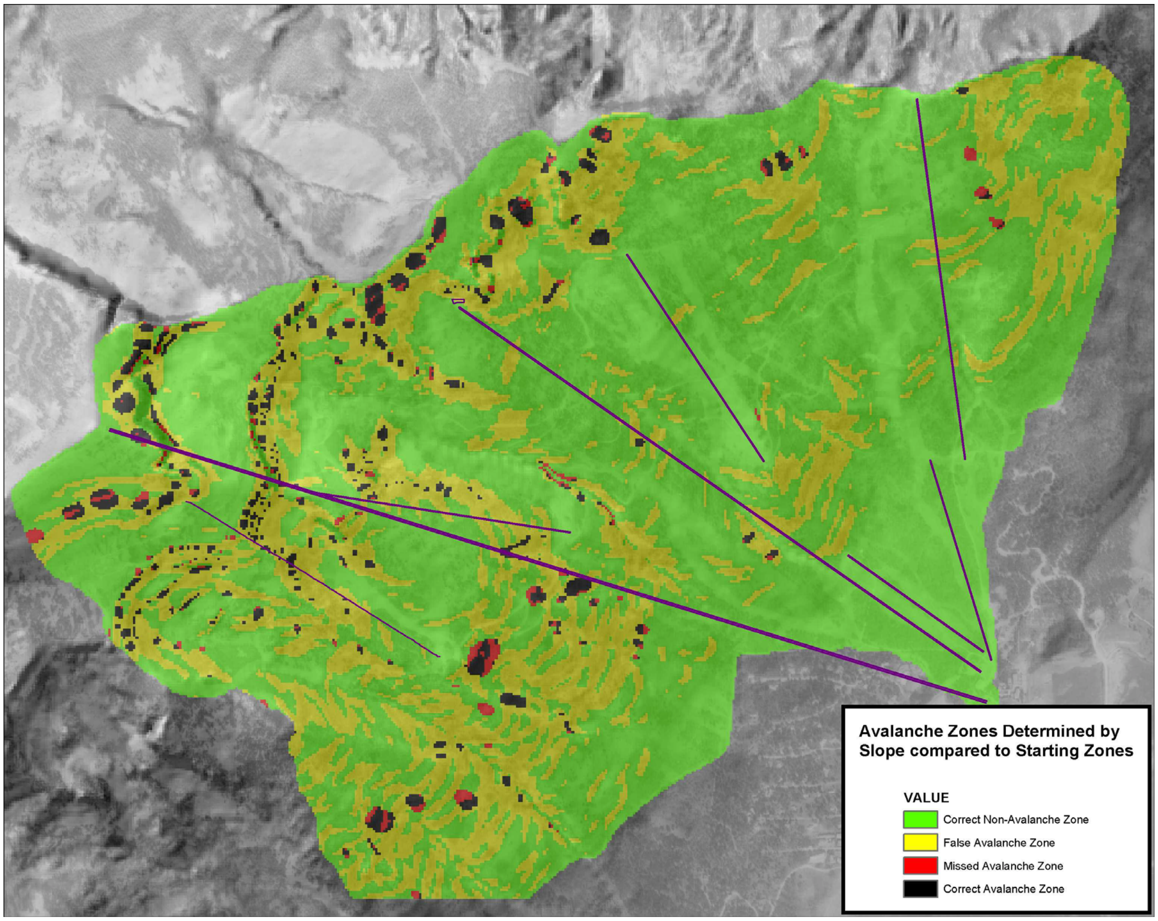

Figure 1: A comparison of GIS mapped avalanche starting zones (with slope angles from 30 to 45 degrees) with the actual starting zones for the Jackson Hole Mountain Resort.

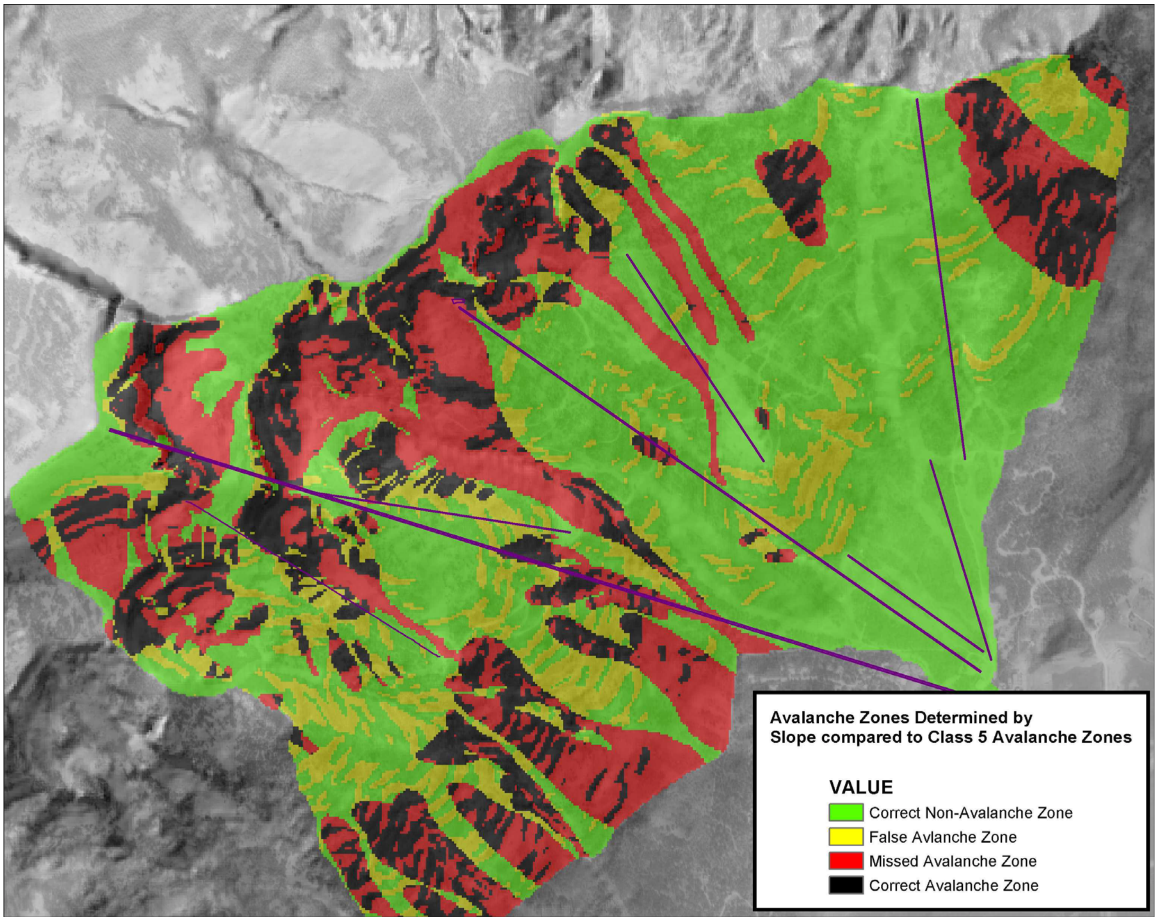

Figure 2: A comparison of GIS mapped avalanche runout zones mapped by slope with the actual runout zones for the Jackson Hole Mountain Resort.

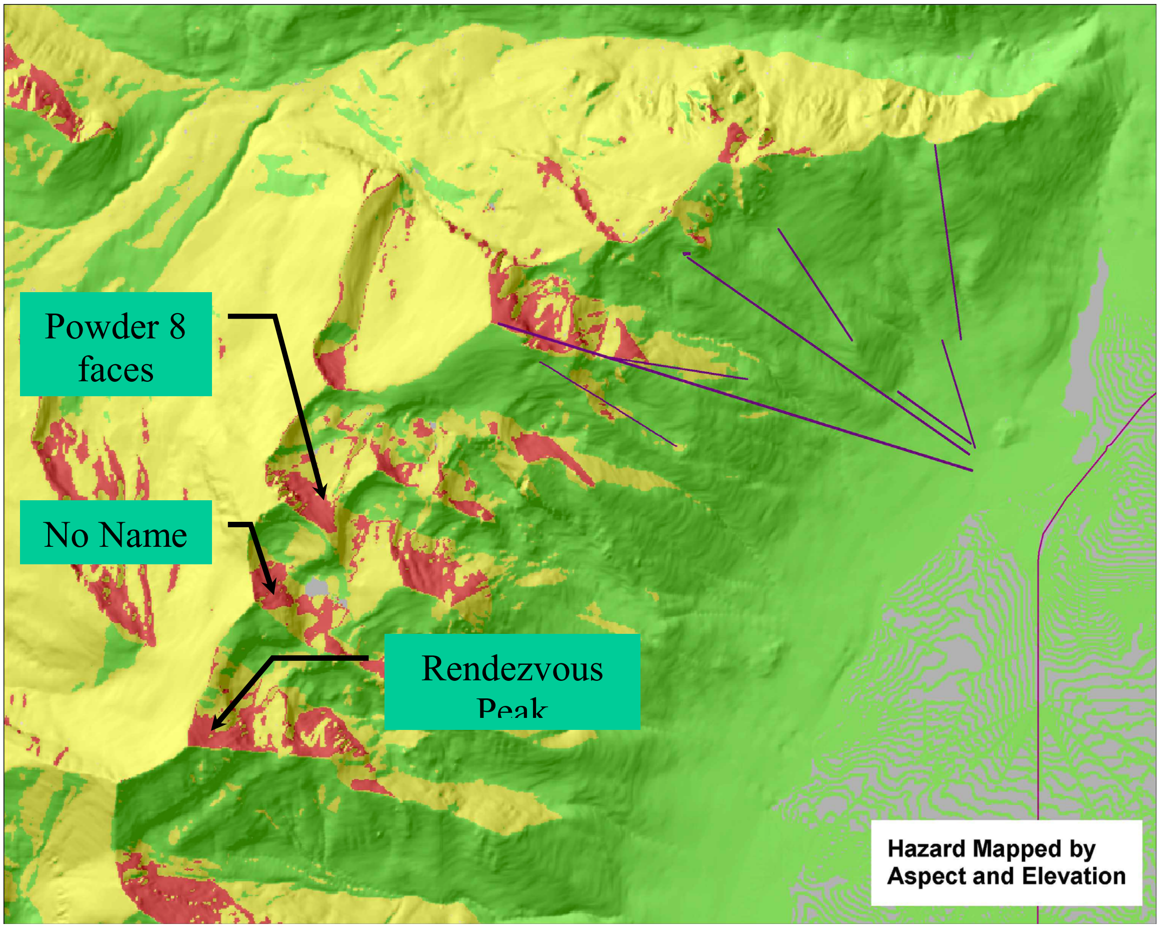

Figure 3: Avalanche danger mapped by elevation and aspect, with the higher elevation north through east aspects having the highest avalanche danger. The three broad faces south of Jackson Hole Mountain Resort, shown in Figure 4, are highlighted.

Figure 4: These three large faces south of Jackson Hole Mountain Resort are, from left to right, Rendezvous Peak, No Name, and the Powder 8 Faces. All have a similar aspect and elevation, and so all would be mapped with the same avalanche danger rating if a GIS was used to map avalanche danger in the area (see Figure 3). However, No Name and the Powder 8 Faces avalanche frequently, while Rendezvous Peak is almost always scoured and rarely has any avalanche danger.

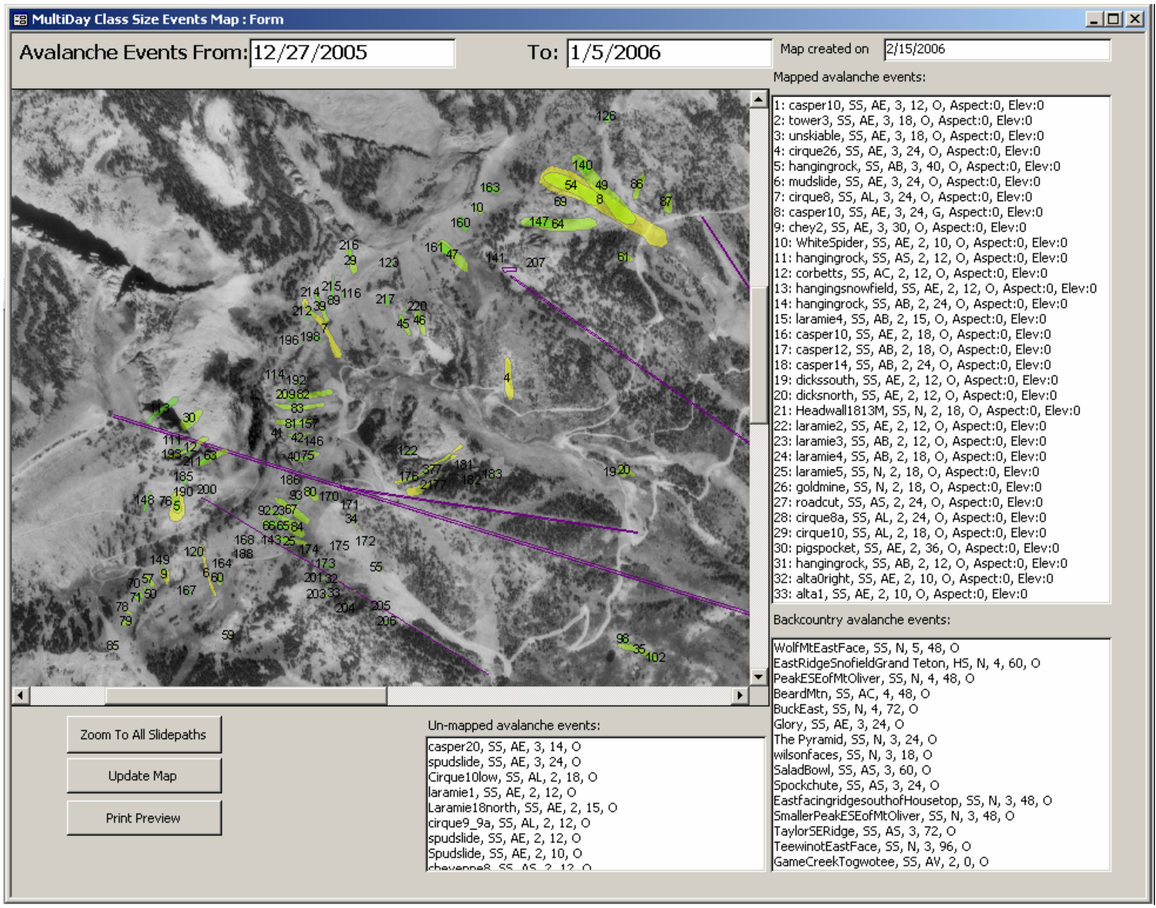

Figure 5: A specialized GIS application at Jackson Hole allows snow safety personnel to visualize the avalanche activity within the area for any given time period. This map graphically depicts avalanche activity within the ski area from 12/27/05 to 1/5/06.

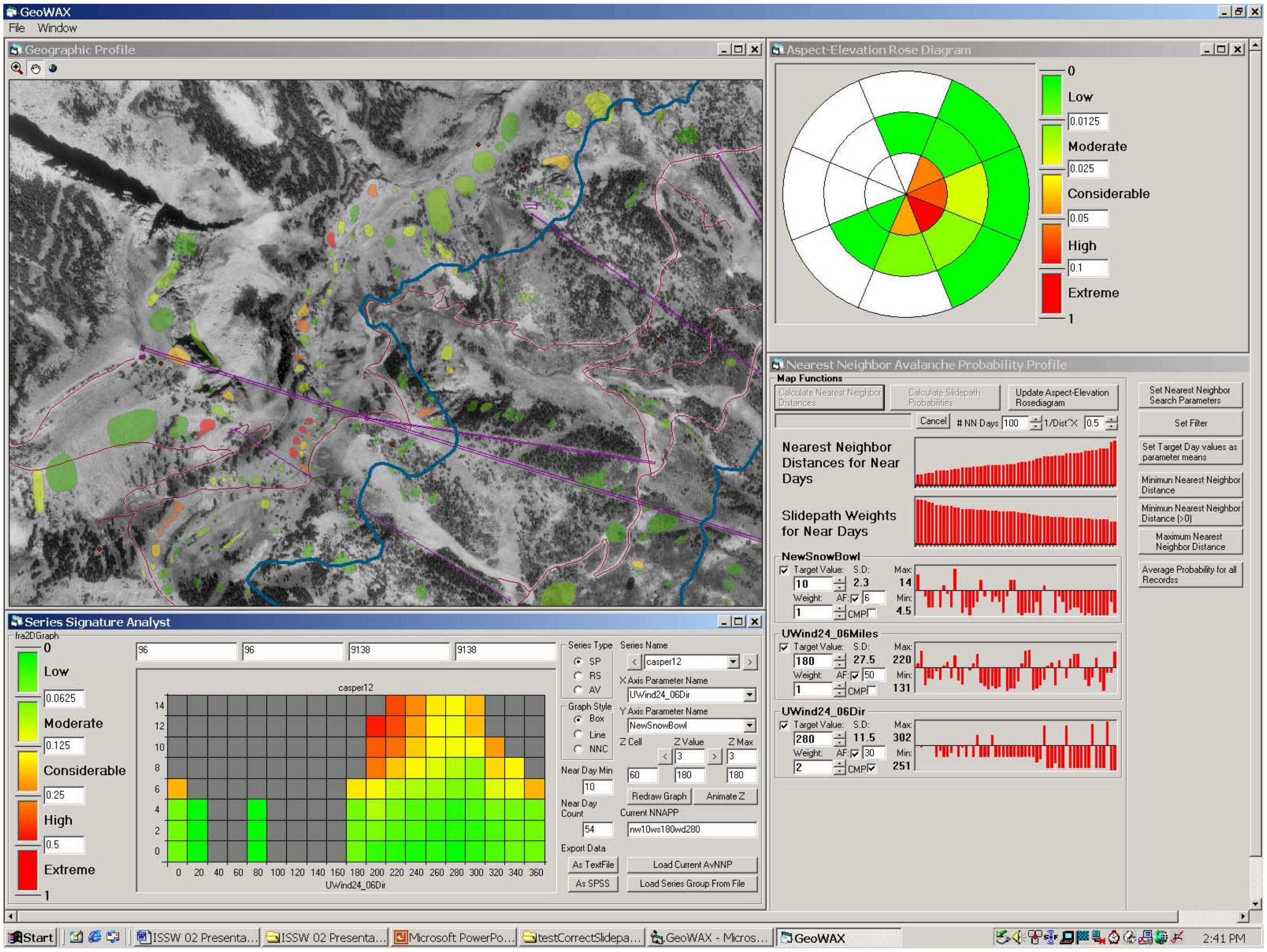

Figure 6: This screenshot shows the user interface for GeoWAX, an application demonstrating the potential promise of GIS for avalanche forecasting. GeoWAX is a spatially oriented tool developed for exploring historical avalanche and weather data at Jackson Hole. Given specific inputs, the tool searches for nearest neighbors and then calculates the probability of individual avalanche paths producing avalanches, and displays a map of those probabilities (McCollister, 2004).