# Using LiDAR (Light Distancing And Ranging) data to more accurately describe avalanche terrain

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ASTRACT: Currently, 30 meter Digital Elevation Models (DEM) and 1 meter color Digital Ortho Quads (DOQ) are available for most of the United States. These readily available spatial data lack the resolution to identify small starting zones, and smooth slope and aspect calculations for larger, identifiable slidepaths. In the summer of 2008, a LiDAR mission was flown for the southeastern Teton Range in northwest Wyoming, USA. One of the primary products of LiDAR data is very accurate and precise bare ground DEMs. This project yielded a 1 meter DEM, along with 15 cm color DOQs. This paper shows examples of raw LiDAR data and their products, which include shaded relief, slope, and aspect maps. The LiDAR data enables better definition of starting zones. Finally, the slope and aspect products are compared to those derived from 10 and 30 meter DEMs. Ultimately, these data create more detailed maps for archiving and displaying avalanche data.

KEYWORDS: LiDAR, GIS, Geographic Information Systems

## 1 INTRODUCTION

The Jackson Hole Mountain Resort, located in southwestern Wyoming, USA, is a Class A avalanche ski area with an active avalanche reduction program. In 2001 and 2002, around 250 in-bound starting zones, along with representative class I through V slides, were digitized with a Geographic Information System (GIS) using a combination of Global Positioning System (GPS) data, a 5 meter Digital Elevation Model (DEM), and 1 meter black and white Digital Ortho Quads (McCollister, 2004). While these data are adequate for many starting zones, they lack the resolution to identify and map smaller starting zones.

LiDAR is a technique to determine distances by the time lag of a laser pulse reflected off of a distant target. When deployed by an aircraft this technique can create a highly detailed, three dimensional surface model of the pulses reflected off the surface of the earth (Figure 1). This raw LiDAR data can be used to create very accurate and precise bare ground DEMs. For more details on the application of LiDAR data for snow and avalanche research, see Deems (2006).

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In cooperation with the Bridger-Teton National Forest and Grand Teton National Park, the Teton County Conservation District organized a LIDAR flight for the southeastern Teton Range in the summer of 2008. This paper utilizes the LiDAR derived data and two other DEMs with resolutions of 10 and 30 m to compare the average elevation, slope, and aspect of 39 starting zones in the Casper Bowl region of the Jackson Hole Mountain Resort.

## 2 METHODS

The LiDAR mission produced 1 meter DEMs and 15 cm color DOQs. These data, along with LiDAR derived contour lines, shaded relief, aspect, and slope grids were used to more accurately identify the location of starting zones in Casper Bowl. Starting zones were then hand digitized utilizing expert knowledge of forecasters, avalanche hazard reduction route leaders, and veteran ski patrollers with extensive experience.

ESRI's ArcGIS 9.2 along with their Spatial Analyst Extension were used to analyze three different DEMs with varying resolutions of 1 m, 10 m, and 30 m. The 1 m DEM was a direct product of the LiDAR flight. The 10 m DEM was created using data from the Engineering Department of the Jackson Hole Mountain Resort. The 30 m DEM was clipped from the USGS National Elevation Dataset (NED). Shaded relief, slope, and aspect grids were subsequently created from each of the three DEMs with varying resolutions.

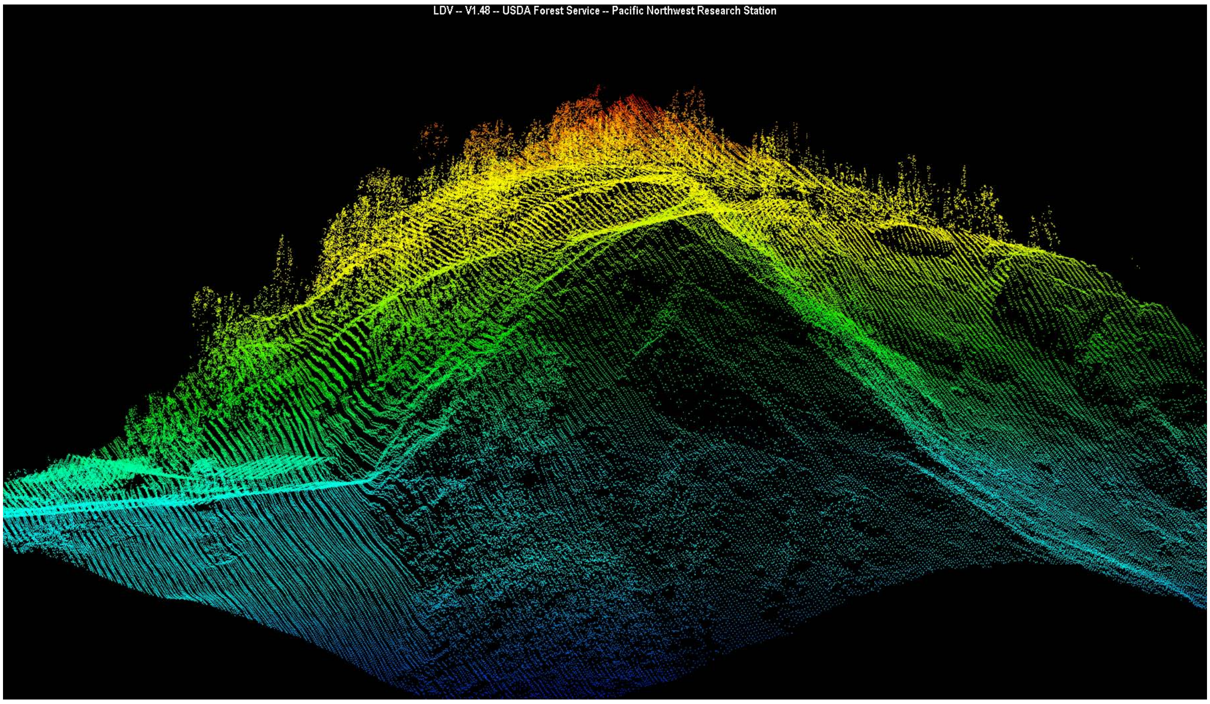


Figure 1. XYZ positions of raw LiDAR radar returns. The linear banding is an artifact of data acquisition. Notice the restaurant in the lower left hand corner and the tree canopy returns.

Using the nine DEM, slope, and aspect grids, zonal statistics were calculated for each starting zone in Casper Bowl. The average elevation and slope of each starting zone were then compared using correction and t-tests. The average aspects of the starting zones were classified using the standard eight direction categories of N, NE, E, SE, S, SW, W, and NW. The counts of starting zones that fell into these categories were compared using a Chi Squared test.

## 3 RESULTS AND DISCUSSION

Using the detail of the LiDAR data along with

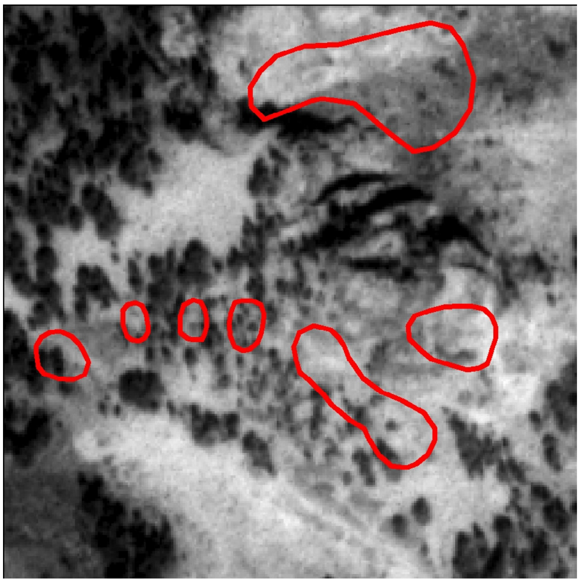

Figure 2. Pre-LiDAR starting zone definitions with a 1 m black and white Digital Ortho Quad.

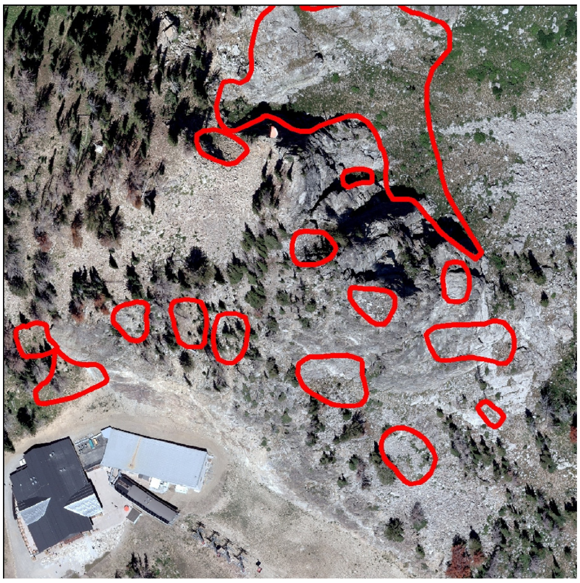

Figure 3. LiDAR derived starting zone definitions with a 15 cm color Digital Ortho Quad.

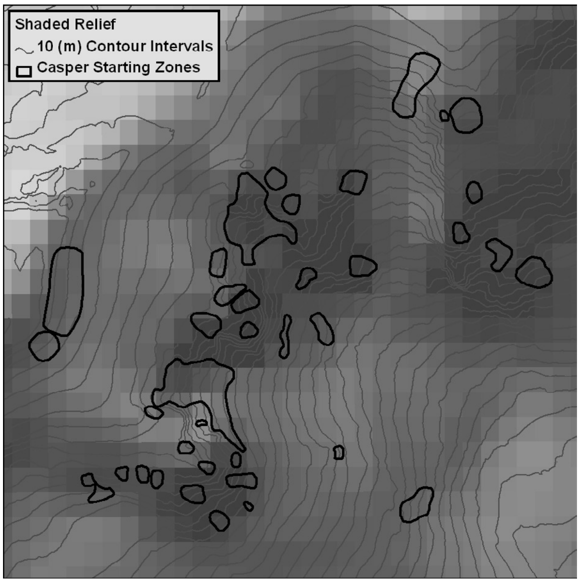

Figure 4. National Elevation Dataset derived (30 m) shaded relief with Casper Bowl starting zones.

expert knowledge, 39 separate starting zones were re-defined from the original 17. Figures 2 and 3 compare a subset of the original starting zones and pre-LiDAR data with LiDAR imagery and redefined starting zones. Table 1 shows summary statistics of cell counts, average elevation, slope, and aspect counts of the Casper Bowl starting zones for the three different resolutions. Notice the dramatic decrease in the cell count as the resolution decreases with most

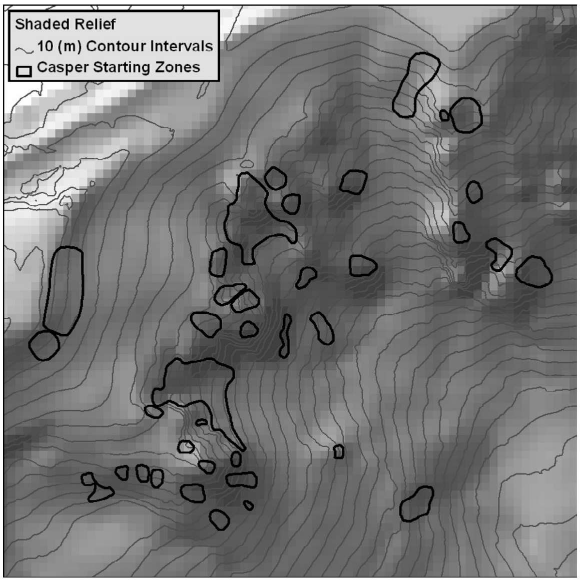

Figure 5. JHMR dataset derived (10 m) shaded relief with Casper Bowl starting zones.

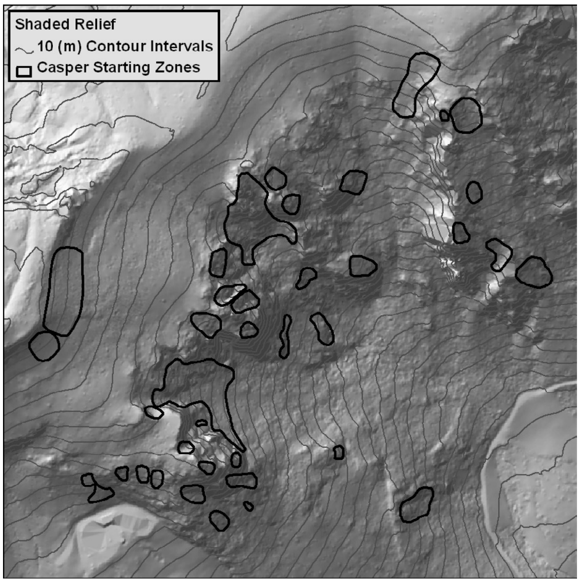

Figure 6. LiDAR derived (1 m) shaded relief with Casper Bowl starting zones.

starting zones only using one or two of the 30 m grid cells.

*3.1 Elevation*

All three DEMs produced very similar results for the average elevation of the Casper Bowl starting zones. The LiDAR (1 m) derived data were nearly perfectly correlated with the JHMR (10 m) derived data ($R^2$ = 0.999999, slope = 0.9993). Their means were not significantly different (t-test: p = 0.889). The LiDAR data were also highly correlated with the NED (30 m) derived data ($R^2$ = 0.999986, slope = 0.9934) and did not

| Starting Zone Grid Cell Statistics | | | |
|---|---|---|---|
| | LiDAR (1 m) | JHMR (10 m) | NED (30 m) |
| Cell Count Mean | 859.2 | 8.8 | 2.0 |
| Cell Count Mode | 191 | 2 | 1 |
| Cell Count Min | 73 | 1 | 1 |
| Cell Count Max | 5514 | 52 | 9 |
| Start Zone Count | 39 | 38 | 24 |
| Mean Elevation (m) | 2796.4 | 2794.6 | 2779.7 |
| Mean Slope | 42.0 | 39.5 | 33.1 |
| NE Starting Zones | 2 | 2 | 0 |
| E Starting Zones | 16 | 13 | 5 |
| SE Starting Zones | 11 | 14 | 12 |
| S Starting Zones | 8 | 8 | 6 |
| SW Starting Zones | 1 | 1 | 1 |

Table 1. Grid cell statistics for different resolutions.

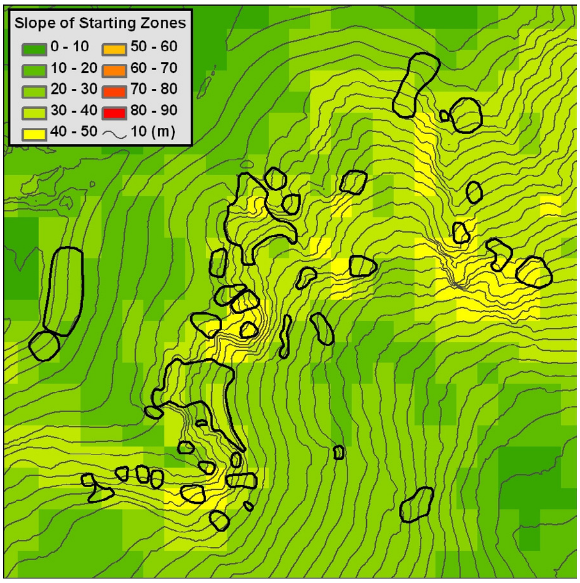


Figure 7. National Elevation Dataset derived (30 m) slope with Casper Bowl starting zones.

significantly differ (t-test: $p = 0.333$). Using a shaded relief grid, figures 4, 5, and 6 display the elevation resolution.

*3.2 Slope*

While all three resolutions produced similar elevation results, the slope measurements were smoothed and decreased as the grid size increased. The LiDAR (1 m) derived slope data

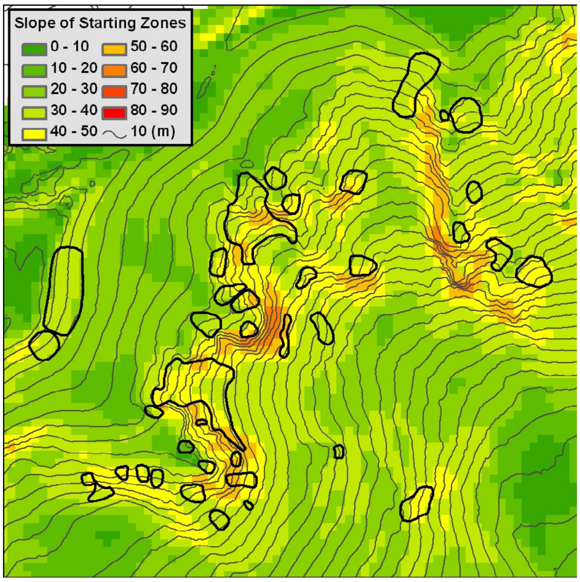


Figure 8. JHMR dataset derived (10 m) slope with Casper Bowl starting zones.

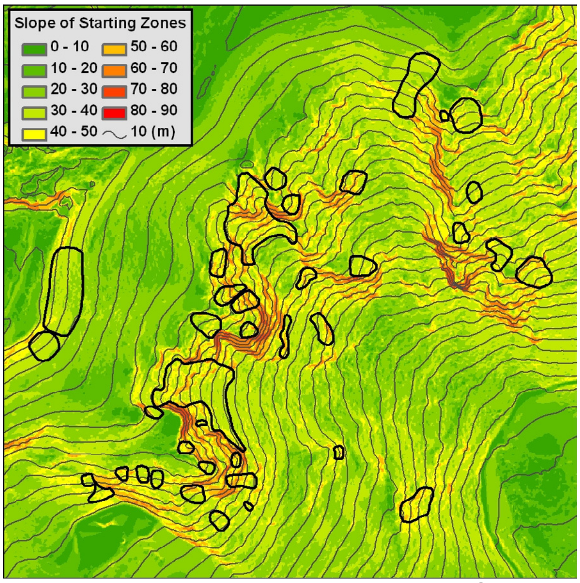


Figure 9. LiDAR derived (1 m) slope with Casper Bowl starting zones.

were highly correlated with the JHMR (10 m) derived data ($R^2 = 0.979$), but the slope was less than one (0.935) producing less steep results with courser resolution grids. Their means were significantly different (t-test: $p = 0.038$). When the LiDAR slope data was compared to the NED data, the effect was more pronounced with a $R^2$ value of 0.957 and a slope of 0.79. Their means were also significantly different (t-test: $p = 0.0001$). Figures 7, 8, and 9 display slope using the same color scheme. Notice the decrease in red colors (steeper areas) as the resolution decreases.

*3.3 Aspect*

When the LiDAR derived aspect data was compared to JHMR 10 m data, there was no significant difference (Chi Squared: $p = 0.855$). In contrast, the LiDAR data was significantly different from the NED data (Chi Squared: $p = 0.027$). There is also a smoothing effect for the aspect data as resolution decreases. The LiDAR derived aspect data are skewed to the east. As the grid size increases, the distribution becomes more normal around the southeast (Table 1). Figures 10, 11, and 12 present aspect using identical symbology, and show a shift to the southeast occurs with orange (northeast) giving way to yellow (east), and yellow being replaced by green (southeast) as the resolution decreases.

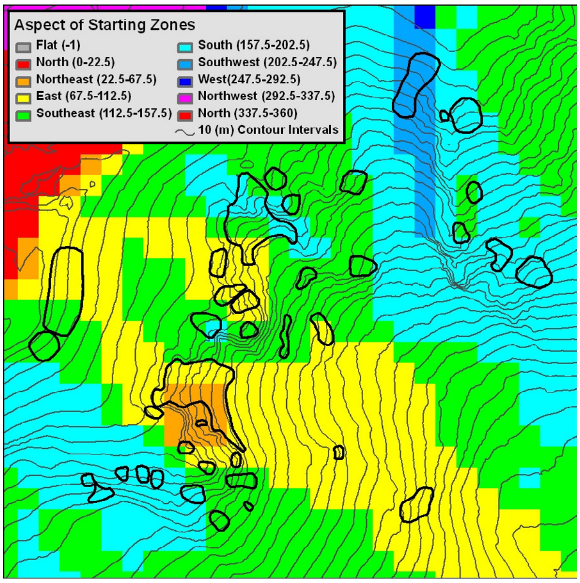


Figure 10. National Elevation Dataset derived (30 m) aspect with Casper Bowl starting zones.

## 4 CONCLUSIONS

Slope decreases and aspect is normalized as resolution decreases. With slope, steep and flat areas cancel each out. Aspect is similar. For example, an east- facing mountain range will have north and south facing gullies and canyons, but the aspect will average out to the east as resolution decreases with the north and south facing aspects cancelling each other out. The

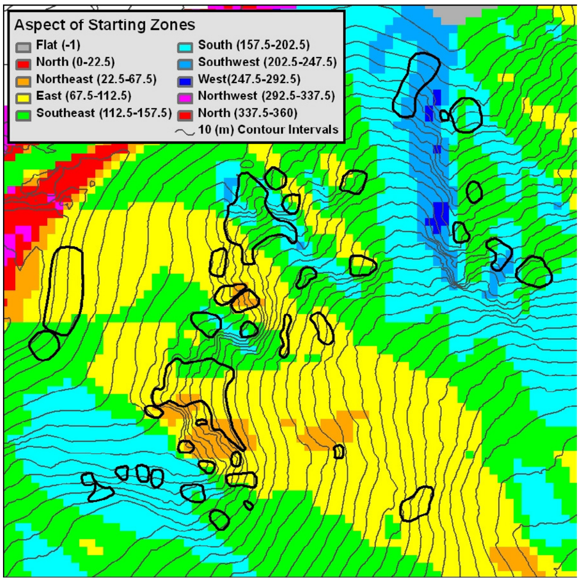


Figure 11. JHMR dataset derived (10 m) aspect with Casper Bowl starting zones.

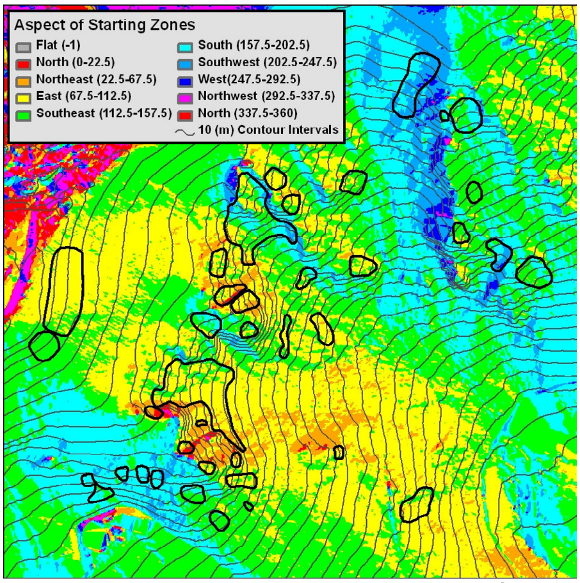


Figure12. LiDAR derived (1 m) aspect with Casper Bowl starting zones.

increased detail of the LiDAR data also helps identify the location of known starting zones.

Similar results were found when comparing all starting zones using the original geographic definitions. McCollister and Birkeland (2006) also found a smoothing effect for slope.

The take home message is 30 m resolution gives good elevation, but slope and aspect are not accurate. Results are improved with 10 m resolution grids, which produce slightly decreased slope values but good aspect data. Not surprisingly, 10 m resolution is better than 30 m, and 1 m resolution is better than 10 m.

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