Using high resolution LiDAR data to estimate potential avalanche release areas on the example of Polish mountain regions.

Pawel Chrustek^{1,2,3}* Piotr Wezyk⁴ ¹ Jagiellonian University, Department of Climatology, Cracow, Poland ² Mountain Rescue Services (GOPR), Podhalanska Group, Poland ³ Anna Pasek Foundation, Bedzin, Poland ⁴ Agricultural University in Cracow, Faculty of Forestry, Lab of GIS & RS, Poland

ABSTRACT: Mountains in Poland (with height over 500 m a.s.l.) cover only 3,1% of the total country area so avalanches are a less serious problem than in e.g. alpine regions. This does not make it less important. Each year in Polish mountains sees a few fatal accidents caused by avalanches. The greatest tragedy took place on the 28th of March, 1968, when the avalanche in the Karkonosze Mountains area killed nineteen people.

GIS technology is widely used for research on snow avalanches, mainly for creating avalanche risk and hazard maps. This technology was also used for mountainous areas in Poland. First GIS analyses in Poland were created in 2004 for selected parts of the Tatra Mountains. The results seem to be satisfying so these activities become increasingly popular in other regions.

The main goal of this study is to compare different types of Digital Elevation Models (DEM), especially with high resolution DEM generated from Light Detection and Ranging (LiDAR) - Airborne Laser Scanning (ALS) data, in the context of estimating potential avalanche release areas and future dynamic calculations in small mountain regions. Study shows how different digital data may influence predictions' results and procedures. Test sites in the Karkonosze Mountains, Sudety and the Tatra Mountains in Carpathian were chosen for this study.

KEYWORDS: snow avalanche, potential release areas, GIS, LiDAR, ALS data, avalanche mapping

1 INTRODUCTION

Mountains in Poland (with the height over 500 m a.s.l.) cover only 3,1% of the total country area, so avalanches are a less serious problem than in e.g. alpine regions. This does not make it less important. Each year in Polish mountains sees a few fatal accidents caused by avalanches. The greatest tragedy took place on the 28th of March, 1968, when the avalanche in Karkonosze Mountain area killed nineteen people.

Snow avalanches in Poland bring also significant damages to forested areas.

GIS technology is widely used for research on snow avalanches, mainly for creating avalanche risk/hazard maps. About 65% of such maps in Europe were created using GIS (Ghinoi, 2003). This technology was also used for mountainous areas in Poland. First GIS avalanche risk maps for selected parts of the Polish Tatra Mountains were created in 2004 (Chrustek, 2005).

The latest studies in Poland aim to implement such research methods as avalanche dynamic calculations, which would allow to create complex cartographic materials on location of avalanche hazard/risk areas.

The first step in avalanche hazard/risk mapping is to generate potential release areas and then to create their topographic characteristics for use in run out calculation.

The most widely used and the most cited method for generating such areas is the method created by specialists from SLF/WSL in Davos. This method generates forestless areas with the inclination between 30 and 60 degrees. Then, based on the types of morphologic terrain forms, their size and the relations between topographic parameters, they are split into autonomous polygons. (Gruber et al., 2002)

This method has a tendency for some level of generalization, mainly because the results are

Corresponding author address: Pawel Chrustek, Jagiellonian University, Cracow, Poland; tel: +48 503 464 819 email: pchrustek@geo.uj.edu.pl

used for analyzing large avalanches. It combines smaller areas into large entities (sometimes excluding some small areas from the analysis). Areas in small, isolated mountain ranges (where avalanches are mostly small or medium, according to the criteria defined by EAWS), are characterized by a significant variety of avalanche activity, so there is a need for their evaluation as separate and autonomous areas. This method is not directly adapted to such areas. Its parameters for use in small mountain regions need to be modified. The following parameters: slope inclination range, input spatial resolution, criteria for area division based on terrain form types, need to be verified (Chrustek, 2005).

This study is a part of the verification described above and its main goal is to compare different types of Digital Elevation Models (DEM), especially with high resolution DEM generated from Airborne Laser Scanning - ALS data, in the context of estimating potential avalanche release areas and future dynamic calculations in small mountain regions. Study shows how different digital data may influence predictions' results and procedures.

Three test polygons were chosen for this study:

- White Gully occupying an area of 24,3 ha, located in the Karkonosze Mountains (part of Western Sudety). The place of the most tragic Polish avalanche accident of 1968, when nineteen people lost their lives. Altogether, twenty people died in avalanche accidents in this area.
- 2. Cirques of Small Lake occupying an area of 59,3 ha, located in the Karkonosze Mountains. Also a place of frequent avalanche accidents.
- Marcinkowski Gully occupying an area of 12,2 ha, located in the western part of the Tatra Mountains (part of the Western Carpathian Mountains). Also a place of frequent avalanche accidents.

2 METHODS

2.1 Data

The following digital data were used for analysis in GIS environment (ESRI ArcInfo 9.2):

a) DEM in GRID format, generated from TIN model based on: contour lines (originated from digitized topographic maps 1:10,000 with 5 m intervals), mass points and hardlines – "traditional models". Models' spatial resolution for all test polygons is 5x5 m.

b) DEM in GRID format as derivative of the interpolation of filtered point cloud, obtained from Airborne Laser Scanning (ALS) (with mean sampling - 4 points/sqm for test polygons no. 1 and 2 and over 20 points/sqm for test polygon no. 3) – "LiDAR models"

Resolution of the interpolated model for test polygons in the Karkonosze Mountains is 0,6x0,6 m, and for test polygon in the Tatra Mountains is 1x1 m.

c) Digital avalanche cadastre in ESRI shape format generated based on photo documentation of historical avalanches.

DEM models generated using topographic maps are the most popular and widely used digital data describing terrain surface in Polish mountain regions (this is also valid for other countries of the Carpathian and Sudety Mountains region). Their significant drawback is generalization of complex terrain forms, but the cost of data acquisition is relatively low.

Quick development of geoinformatic technologies introduced laser scanning, which became a serious competitor for traditional metering methods. Its main strength is efficiency when creating large scale studies with high precision, or integration of scanning technology with sensors recording optical wavelengths (large airborne resolution imaging, hyperspectral scanners, and thermal imaging cameras) (Wezyk, 2006).

Laser scanning known as LiDAR (Light Detection and Ranging) is a member of the remote sensing systems group, using most commonly NIR (Near InfraRed) radiation for imaging.

In general, laser scanner measures the distance from the device to the target. This is performed by measuring the time flow between emitting the light wave and its return to the detector, after having been reflected by the target surface. As the electromagnetic wave propagation speed and measured time flow values are known, they allow to calculate the distance from the scanner to the target.

Scanner device enables to register an angle of the emitted light beam (this value can be controlled). Time and beam angle parameters explicitly allow to determine measured points coordinates in three-dimensional space (Wezyk, 2006).

Polygons ID	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
type of DEM	topo 5 m	topo 5 m	topo 5 m	topo 10 m	topo 10 m	topo 10 m	topo 25 m	topo 25 m	topo 25 m
PRA areas [ha]	8,5	21,0	4,9	8,5	20,8	4,6	7,5	19,9	4,1
type of DEM	LiDAR 5 m	LiDAR 5 m	LiDAR 5 m	LiDAR 10 m	LiDAR 10 m	LiDAR 10 m	LiDAR 25 m	LiDAR 25 m	LiDAR 25 m
PRA areas [ha]	8,6	21,8	4,8	8,3	21,5	4,6	7,4	20,9	4,2

Table 1. PRAs generated from different models with different resolutions.

Based on scanner location in geographic space, we can distinguish the following technologies that are using it, Airborne Laser Scanning (ALS), Satellite Laser Scanning (SLS) and Terrestrial Laser Scanning (TLS) (Wezyk, 2006).

2.2 Generating Potential Release Areas (PRAs)

As the base PRA, a forestless terrain with the inclination angle between 28 and 60 degrees was assumed.

For comparative analyses, the input DEM models (traditional and LiDAR) were resampled to the same spatial resolutions of 5, 10 and 25 meters, which are the most widely used resolutions for generating primary PRAs (e.g. Gruber, 2001; Gruber et al., 2002; Gruber and Bartleit, 2007). Generating PRAs from LiDAR models with resolution below 1 m does not seem to be justified, as precise terrain differentiation disappears under snow cover, which causes natural process of "smoothing" the surface.

The size of generated PRA surfaces for various model types and resolutions is presented in table 1.

2.3 Generating landforms

Slope topography in longitudinal and cross section has an impact on tension state in the snow pack and on the size of the possible snow accumulation. Comparative analyses for this scope of research were made as automatically generated terrain forms are the basis for collating PRAs to autonomous polygons (Gruber et al., 2002). They can also be used for dynamic calculations (auxiliary for determining types of terrain forms on separate sections of avalanche flow - when using dynamic 1D models).

This analysis required generating (for entire polygons' surfaces) terrain forms in cross section profile using "Planar Curvature" tool (ArcInfo).

Terrain forms were divided into concave, flat and convex, using -0.2 - 0.2 criterion (Gruber et al., 2002).

For comparative purposes, traditional and LiDAR models were resampled to the same spatial resolutions of 10, 25 and 50 meters. The results of these conversions and percentage structure of generated forms are shown in table 2.

DEM resolution [m]	10				25		50				
landforms (planar curvature -0,2 - 0,2)	concave	flat	convex	concave	flat	convex	concave	flat	convex		
Polygon 1 - White Gully (Karkonosze Mountains) [% of total area]											
Topo DEM	36	29	35	30	43	27	24	63	13		
LiDAR DEM	40	16	44	28	46	26	24	65	11		
Polygon 2 - Small Lake (Karkonosze Mountains) [% of total area]											
Topo DEM	37	31	32	32	41	26	24	63	13		
LiDAR DEM	40	17	43	31	41	28	27	61	13		
Polygon 3 - Marcinkowski Gully (Tatra Mountains) [% of total area]											
Topo DEM	40	11	49	33	22	45	30	32	38		
LIDAR DEM	41	10	49	34	22	44	31	35	35		

Table 2. Percentage structure of automatically generated terrain forms (Planar Curvature, ArcInfo)

Hydrologic flow analysis in avalanche hazard/risk mapping is used, among others, auxiliary in the context of determining main profile of avalanche flow (as the input parameter in 1D calculations and statistical analyses). Its precise transformation on DEM model has an impact also on dynamic 2D calculations' results (Casteller et al., 2008).

Transformation results on the highest analysed resolution (0,6 m) LiDAR models indicate a very high compliance between stream lines generated automatically and stream lines occurring in real life (visual comparisons were made based on orthophotomaps). Compliance is lower in traditional models (with the resolution of 5 m and lower), which is visible especially when considering complex terrain forms.

For comparison purposes, the example stream lines were generated for test polygon no. 1 (from traditional and LiDAR models with the same resolution 5 m), using Flow Accumulation tool (ArcInfo). This case also demonstrated that LiDAR model is more precise. Local changes in flow profile are reflected in real avalanche flow mechanics (Figure 1).



Figure 1. Stream lines generated automatically (ArcInfo) for test polygon no. 1, in comparison with real deadly avalanche flow from 2008. Continuous line shows stream line generated from LiDAR model, dash-dot line - traditional model, triple dash-dot line - real avalanche outline. Arrows indicate compliance of local changes in profile generated from LiDAR model and high deposit.

GIS hydrologic analyses were the first step in generating autonomous PRAs and were performed by scientists from WSL/SLF in Davos. But this approach was abandoned in favour of another one that is related to the curvature of the terrain (Gruber et al., 2002). Considerable usefulness of LiDAR terrain models in hydrologic analyses has motivated the authors of this study, to create similar analysis for test polygon no. 2 (using the basic ArcInfo tool – Basin). It was based on terrain models of the highest available resolution (0,6 m for LiDAR model and 5 m for traditional model). 5 m resolution for relatively small area has been found insufficient, resulting in generating heavily generalized borders of basins areas (Figure 2). Very interesting results were obtained from LiDAR model (0,6 m), also shown on figure 2.



Figure 2. Result of the automatic Basin analysis (ArcInfo) for test polygon no. 2. Basins for LiDAR model (with resolution of 0,6 m, in PRA borders between 28 and 60 degrees of inclination) are indicated by various shades of grey. Continuous lines show Basins generated from the traditional model (5 m), dash-dot lines indicate outlines of historical avalanches. Arrows show examples of compliance between location of avalanche verge and Basins division (using hillshade underlay of LiDAR DEM 0,6 m).

3 RESULTS AND DISCUSSION

Performed analyses, even though not fully comprehensive, allow to obtain a few interesting observations.

When comparing automatically generated base PRAs from traditional and LiDAR models (for common spatial resolutions -5, 10 and 25 m), there are no noticeable quantitative differences. The biggest differences (up to 0,8 ha) can be seen in test polygon no. 2, but it is worth mentioning, that it is the largest analyzed test polygon in this study and it has the most complex terrain surface (glacier cirques). For the other test polygons, the differences have not exceeded 0,2 ha.

It may lead to the conclusion, that LiDAR models resampled to smaller resolutions generate very similar results when compared to traditional models. However, additional assessment of the results shows that local spatial differences occur in generated areas. They are the most distinct in steep areas (with inclination higher than 60 degrees) and in complex terrain. LiDAR models are noticeably more precise there (including those resampled to smaller resolutions).

This observation is confirmed by maximum values of slope inclination in generated areas. As an example, for test polygon no. 2, 86 degrees was obtained as the maximum value for LiDAR model 0,6 m, 74 degrees for LiDAR model 5 m and 60 degrees for traditional model 5 m.

Some quantitative differences are noticeable when analysing surface and structure of generated terrain forms. Those differences are significant for the larger resolutions (up to 14% in flat areas for test polygons no. 1 and 2 – DEM 5 m) and are fading proportionally to decreasing model resolution. For analysed resolutions of 25 and 50 m those differences are between 0 and 3%, so they are relatively very small.

In this case, visual assessment confirms spatial differences regarding precision of forms location, to the advantage of LiDAR models.

The significant advantage of LiDAR models over the traditional ones were observed while making simple hydrologic analyses (stream lines and basins). Such analyses are especially important for generating base PRAs (and later segregation) for future dynamic calculations.

It is very probable that the use of more advanced GIS hydrologic tools allows to obtain even more interesting results from LiDAR models.

It appears that all mentioned strengths of LiDAR models may have particular importance for avalanche mapping in smaller mountainous regions, where majority of avalanches are small or medium and their frequency is closely related to the local changes of terrain form.

Interesting outcome of the analyses is likely to motivate authors of this study for further, more advanced research in the Carpathian and Sudety Mountains region. For the forthcoming analyses, as mentioned at the beginning, it is planned to include 1D and 2D dynamic calculations, as well as to use Terrestrial Laser Scanning (TLS) data, that will allow more complex evaluation of available digital data in the context of avalanche hazard/risk areas mapping.

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