



Item	Value
File Signature	
File Source ID	
Revision	
Project ID (GUID)	
Version	
System Identifiers	
Generating Software	
File Creation Day of Year	
File Creation Year	
Header Size	
Offset to point data	
Number of variable length records	
Point Data Format ID	
Point Data Record Length	
Number of point records	
Number of points for return 1	
Number of points for return 2	
Number of points for return 3	
Number of points for return 4	
Number of points for return 5	
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Max X	
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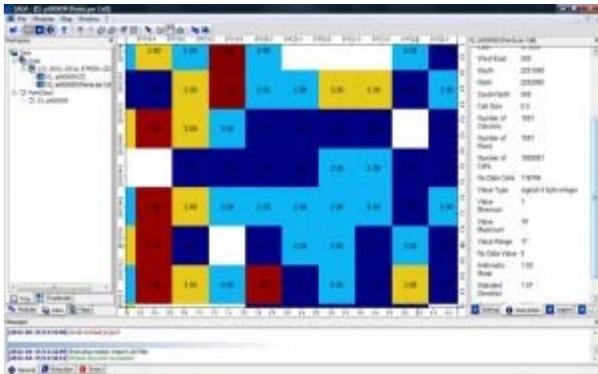
Header information read by LP360

Many data providers will also supply a detailed project report including information on the project's error budget, ground control networks, flight conditions, and other technical details.

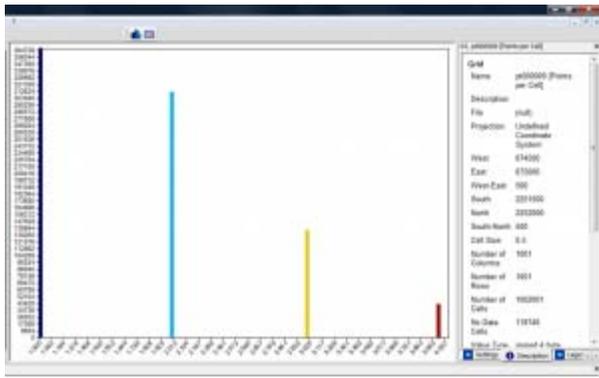
## Checking the Point Density.

Knowing the real resolution of your lidar data is important. Checking that it matches your requested resolution is an essential part of quality control in an ALS project. This information will affect the parameters you select for classification and interpolation; It may also influence your expectations regarding the types of features you should be able to identify or accurately measure.

In LASTools you can use the '-cd' or '-compute\_density' option in [LASInfo](#) to compute a good approximation of the point density for the file. Alternatively, you can use [SAGA GIS](#), an open source GIS software package, to plot per grid cell density and visualize how the densities vary across your dataset.



Points per grid cell visualized in SAGA.



Histogram of points per grid cell, visualized in SAGA.

## Sources of ALS Errors.

The total error for a lidar system is the sum of the errors from the laser rangefinder, the GPS and the IMU. These sources of error and the calculation of error budgets have been discussed extensively in the literature, including good summaries by Baltsavias (1999) and Habib et al. (2008). For ALS surveys conducted from fixed-wing aircraft platforms, these often total somewhere between 20 and 30cm.

The main sources of error are:

- Platform navigational errors
- GPS/IMU navigational errors
- Laser sensor calibration errors (range measurement and scan angle)
- Timing resolution
- Boresight misalignment
- Terrain and near-terrain object characteristics

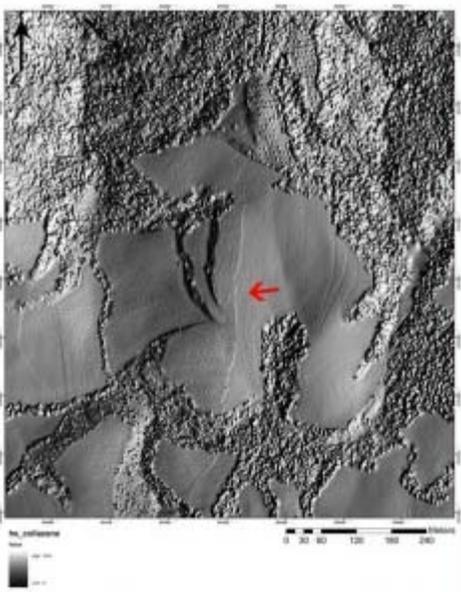
Errors may be vertical (along the Z axis) or planimetric (shifts on the XY plane). The errors are obviously related, but they are usually quantified separately in accuracy reports. In commercial applications accuracy analyses usually focus on vertical accuracy, while planimetric accuracy (XY) is secondary.

## Types of Errors.

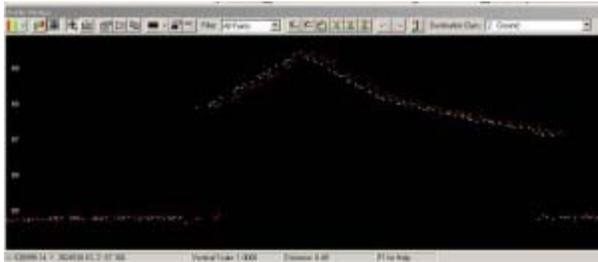
Both horizontal and vertical errors may be described as random, systematic or terrain dependent. The main source of random error is position noise from the GPS/IMU system, which will produce noise in the final point cloud. These coordinate errors are independent of the flying height, scan angle and terrain.

Systematic errors include errors in range measurement, boresight misalignment, lever arm offset and mirror angle, and some errors from the GPS/IMU system (e.g. INS initialization and misalignment errors and multi-path returns). These errors will appear throughout the dataset. Terrain dependent errors derive from the interaction of the laser pulse with the objects it strikes. In steeply sloping terrain or areas with off-terrain objects, and at higher scan angles, beam divergence may be increased and result in vertical errors due to horizontal positional shift.

Errors are most visually apparent in areas of strip overlap. A characteristic sawtooth pattern seen in hillshaded DTMs and clear misalignments of planar roof patches seen in the profile are typical of misalignment between adjacent strips.



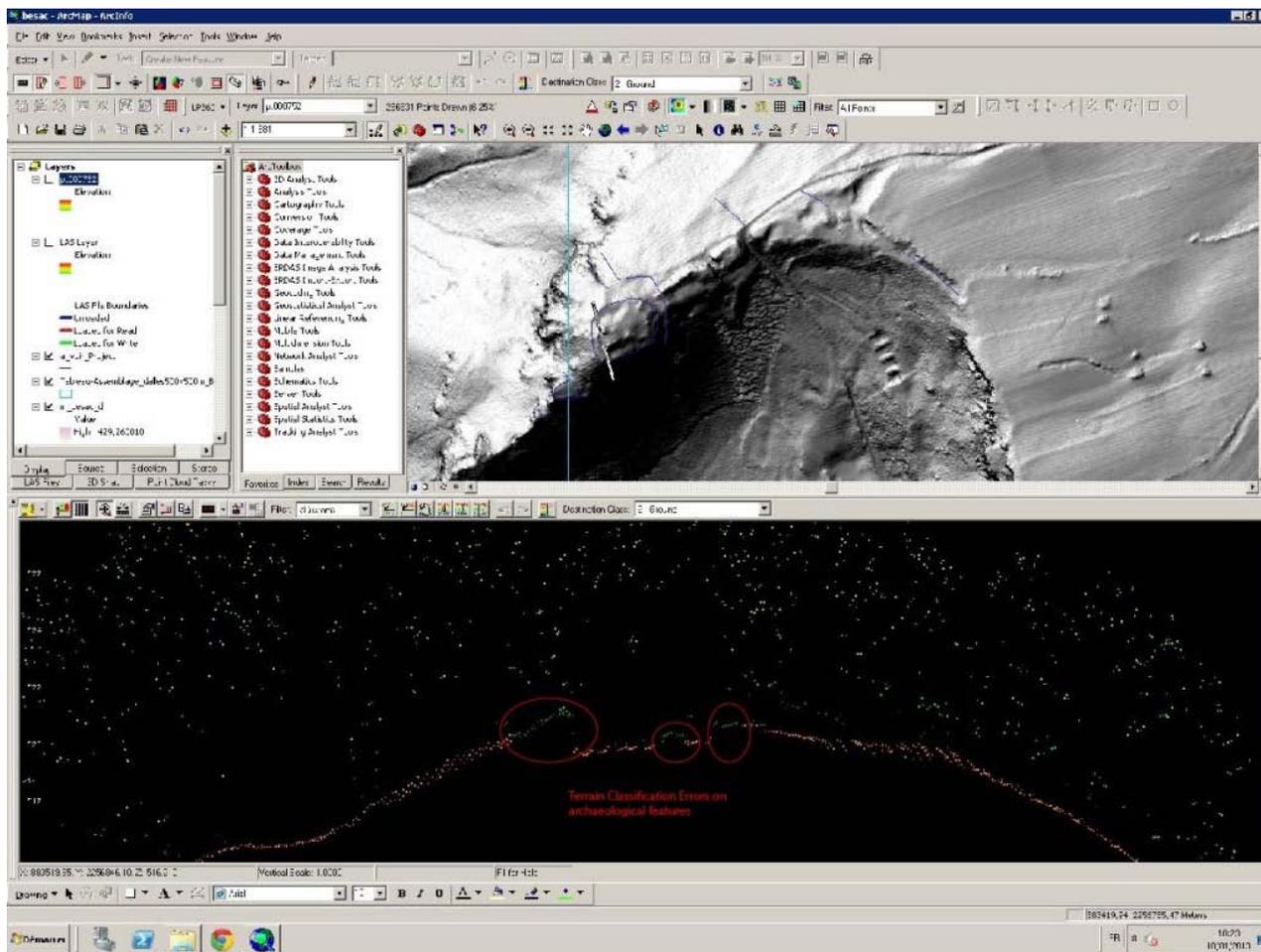
Strip overlap errors seen in a hillshaded DTM.



Two scans of the same roofline in two overlapping strips are slightly offset, indicating a slight error. Points coloured by flightstrip.

## Classification Errors.

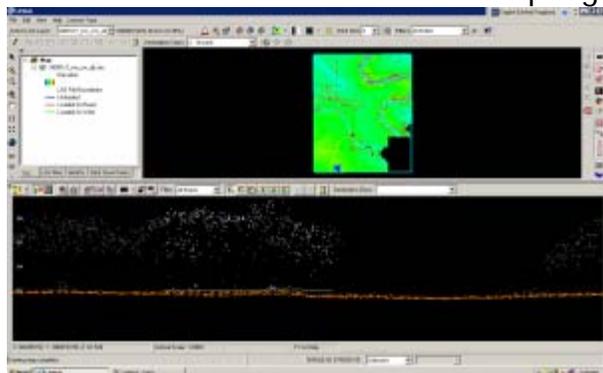
Lidar data is typically gathered across large areas of the landscape, which may include woodland, urban and arable areas. One of the advantages of lidar over other remote sensing technologies is its ability to 'see through' the vegetation canopy, as some returns will pass through gaps in the canopy, reaching and returning from the ground- allowing the creation of a bare earth DEM. To accomplish this data must be classified (or filtered) to separate returns from terrain and off-terrain objects.



Points incorrectly classified as low vegetation (dark green) which should be terrain (orange).

There are a number of algorithms in use for classifying a point cloud. Regardless of the algorithm used, some errors will be committed. Two types of classification errors occur when performing a classification: the removal of points that should be retained (type 1) and the inclusion of points that should be removed (type 2). Overly aggressive algorithms or parameter settings have a tendency to remove small peaks and ridges in the terrain and to smooth or flatten the ground surface. Conversely, insufficiently aggressive parameters will induce the inclusion of clumps of low vegetation returns in the ground class, and can result in false 'features'

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<http://gmvc.cast.uark.edu/scanning/airborne-laser-scanning/als-data/bayou-meto-lidar/#comments> Fri, 18 Jan 2013 10:00:45 +0000 Rachel <http://gmvc.cast.uark.edu/?p=11889> [Continue reading →](#)]]>



ALS data from the Bayou Meto undergoing

processing

CAST researchers and student assistants developed a hydro-enforced DTM (Digital Terrain Model) covering the Bayou Meto watershed, in collaboration with the NCRS and Arkansas Natural Resources Commission. The classification of the raw ALS data, interpolation to basic bare-earth terrain models, the creation of breaklines and streamlines for hydro-enforcement, and the refinement of final hydro-enforced models were carried out at CAST.

Data for this project was collected by Aeroquest in 2009 and 2010 for two areas within the Bayou Meto, at a nominal resolution of 10 pts/m<sup>2</sup>. The [TIFFS](#) and [LP360](#) software packages were used to process the discrete return ALS data and to assist in breakline production.

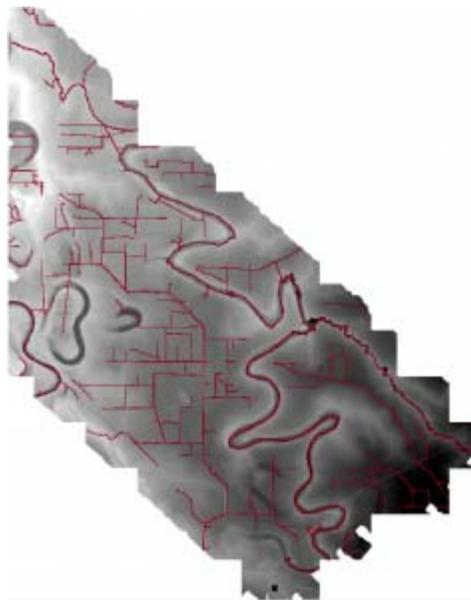
For more information, see the [main project webpage](#).

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## DTMs

ALS data can be used to create a number of products based on elevation data. The most common ALS product created is the bare earth DTM. The bare earth DTM provides the basis for analyses in hydrology, flood risk mapping, landslides, and numerous other fields.

Hydro-enforced DTMs include breaklines, importantly stream centerlines and edges, and breaklines delimiting standing water bodies such as ponds. While auto-extraction of breaklines is improving, the creation of hydro-enforcing features is still by and large a manual task.

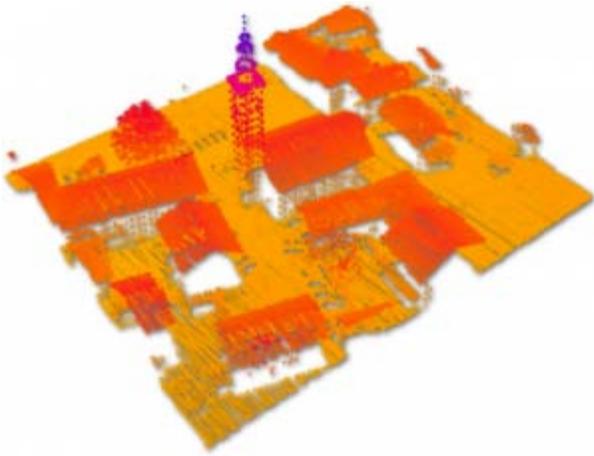


Deliverables include hydro-DTMs.

## DSMs

Digital Surface Models (DSMs) can include only returns from the terrain, buildings and specific classes of off-terrain objects like bridges, or can also incorporate returns from vegetation. DSMs are commonly used in urban environment analyses such as noise pollution modeling and inter-visibility analyses to assess the

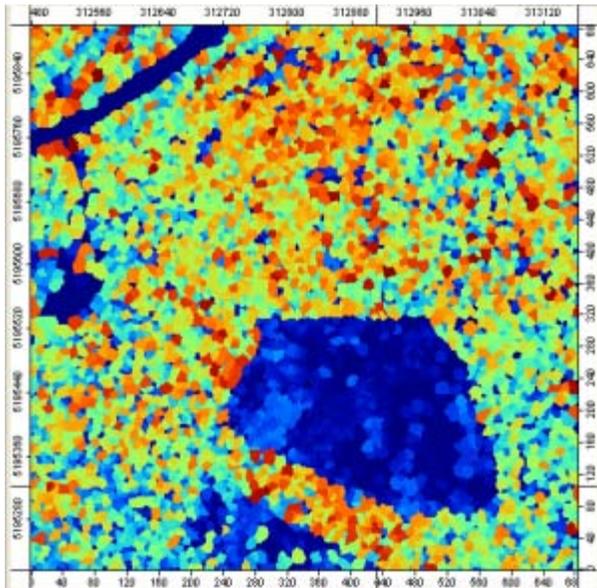
impact of new building.



DSMs are often used for modeling in urban areas.

## CHM

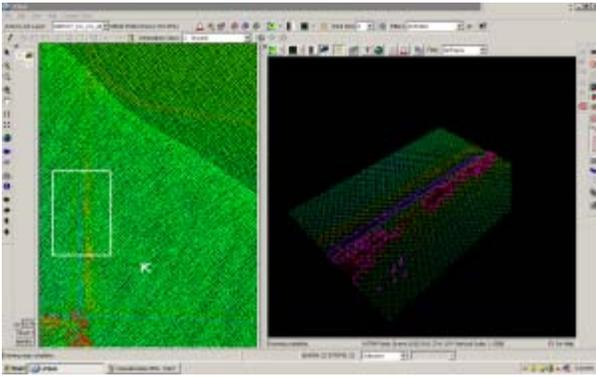
Canopy height models, and per-stand or individual tree metrics are important ALS-based products for forestry applications. These models often include returns separated into low- mid- and high- vegetation classes, and are sometimes normalized based on local terrain heights to facilitate comparisons between different forest areas.



Canopy height model generated using SAGA GIS.

## Contours

Contour maps at standard intervals, e.g. 1m, 5m, or 20m contours, can be generated from bare earth DTMs. Contour maps can be generated with or without breaklines.

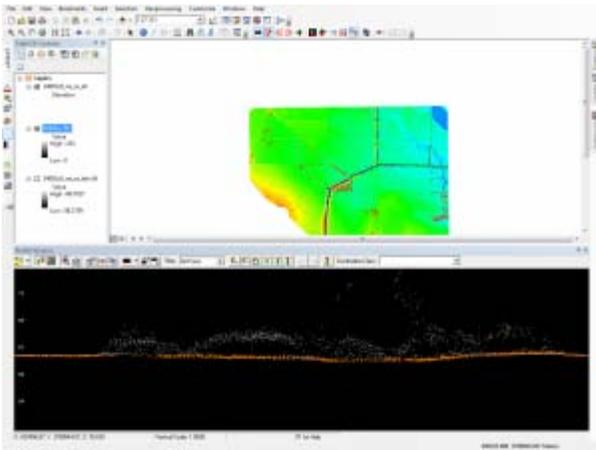


Contours developed based on the terrain model.

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## Initial Automatic Classification

In most ALS projects, in the first instance, the data is automatically classified. No automatic classification is perfect, and therefore visual assessment and the manual re-classification of some returns are important steps in the creation of a high quality hydro-enforced terrain model, and the development of other derivatives of ALS point clouds. The Bayou Meto terrain model developed at CAST was processed using [TIFES](#), a software program which implements a morphological filter. Other good low cost or open source software for automatic classification includes [LASTools](#) and [MCC-Lidar](#).



Automatically classified Point Cloud seen in profile. Terrain points (class 2) are orange, and off-terrain points are grey.

## Create DTMs and Hillshades

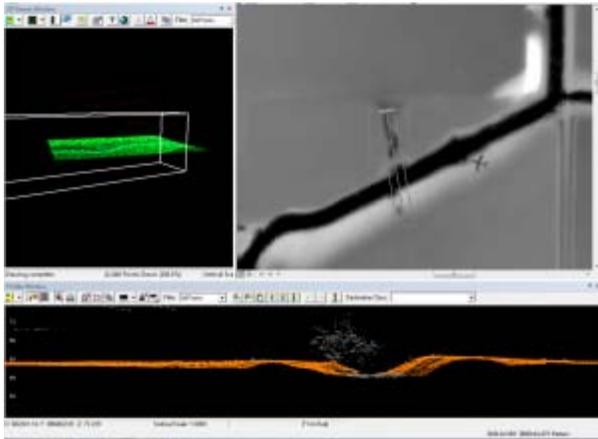
To facilitate visually identifying incorrectly classified returns, it's useful to interpolate the automatically classified ground points into a DTM, and to create basic hillshades. Many classification errors will be readily apparent in the hillshaded models. The DTMs for the Bayou Meto project were created using [LP360 for ArcGIS](#).



Bare earth DTM created before manual re-classification.

## Linked Viewers

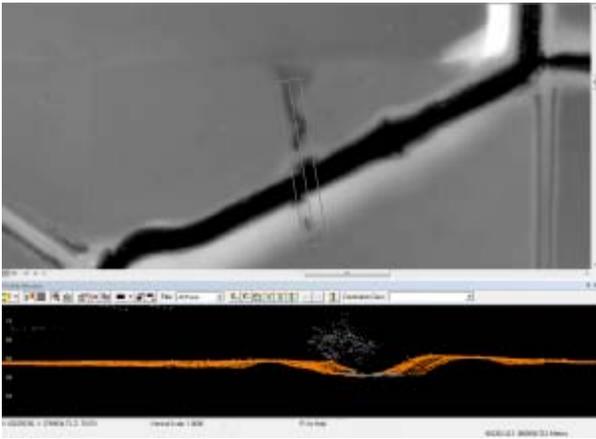
Viewing the point cloud simultaneously with the hillshaded terrain model, you can navigate quickly to 'problem areas' to re-classify any incorrect points in the ALS point cloud.



Linked viewers allow simultaneous viewing as a 3d point cloud, in profile, and at a shaded DTM.

## Drawing Profiles

Draw a profile across an area of the terrain model where potential mis-classifications have been identified. Depending on how regular the terrain surface is, set the depth of the profile. Areas where the elevation of the terrain varies greatly generally require narrower profiles to clearly visualize the separation between the ground surface and low vegetation.



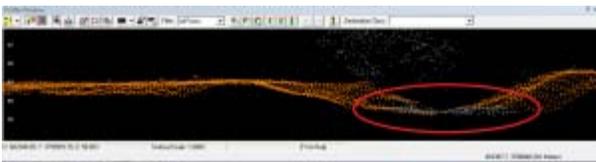
Drawing the profile on the DTM.

## Editing classifications

When editing the classification of the points it's best to set the point cloud coloring style to 'by class' rather than by elevation or by return, as it's then easier to see which points should be re-classified. In LP360 you can change the classification of points by selecting them in the profile view using a 'brush' or 'lasso' tool and then typing the number of the class they should be and hitting enter.

## Typical problem areas

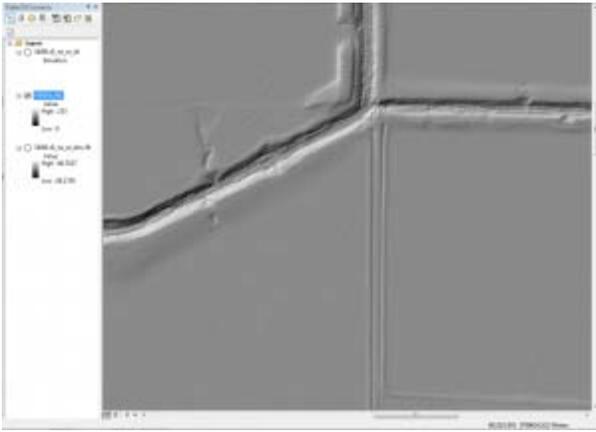
Work across the dataset systematically, until all problem areas have been improved. Note that areas with dense, low vegetation, large numbers of small buildings, and mixed steep slopes and vegetation are the most likely to contain mis-classified returns, and will require more effort. In the Bayou Meto dataset, the edges of streams proved typical problem areas, combining sloping terrain and low, dense vegetation.



Typical problem area circled in red, located under vegetation at the base of the slope.

## Re-creating the terrain models

After re-classifying the ALS returns, it is necessary to re-create the terrain models and any other derivatives. These new models are the basis for further processing and analysis.

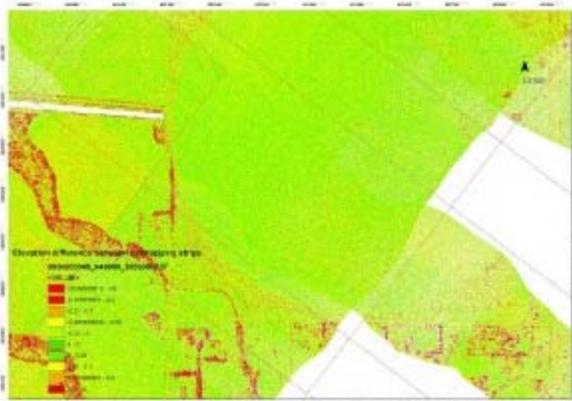


Hillshades and other derivatives are created from the cleaned point clouds.

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## ALS data

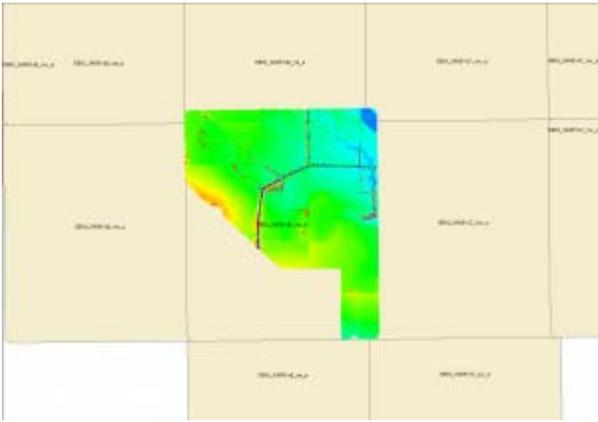
ALS data is often collected in strips, with each strip representing an individual flightline. Typical ALS surveys have at least 20% overlap between adjacent flightlines and a few cross-strips where data is collected at an orientation perpendicular to that used for the main survey, improving accuracy.



A tie strip can be seen here overlapping with two flightlines.

## Tile Schemes

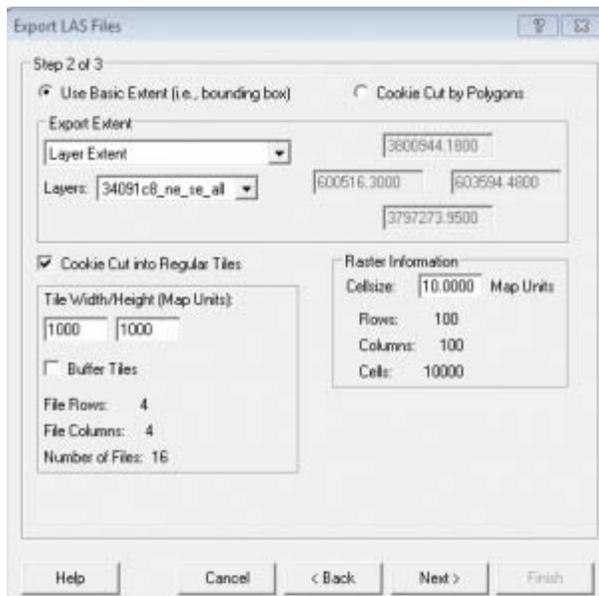
Because ALS datasets are usually very large, they are often divided into regularly sized tiles. These tiling schemes can help with the speed of data loading, and allow users to load areas of the dataset selectively for processing or analysis.



Tiles represent .las file locations, one file is loaded. Note that the tiles are regular rectangles, and don't always exactly match the extents of the .las file.

## LP360 tiling tools

LP360, like most ALS software, provides tools to perform the tiling task. Typical tile sizes include 0.5×0.5km or 1x1km tiles. The naming convention for the tiles should follow a sensible progression, for example reflecting official map grid designations for the area, or following an east to west progressive sequence across the survey area.



The LP360 .las subsetting tool

## Creating Footprints

A vector file containing the footprints for each tile, designating the area covered and linking to the .las file or derived terrain models, are a common way of efficiently representing the ALS dataset in a GIS environment. Using LP360, individual files or groups of files can be loaded by selecting their footprints.



Las file footprints are outlined in dark blue; a selected footprint is highlighted.

## Metadata

Metadata for ALS is typically generated for the entire survey, rather than per tile. This project level metadata is usually stored in a long form report. That said, some metadata will be stored in the .las header for each tile. Attributes including the total number of points in the file, whether or not it has been classified, and the software used to process the data are typical items found in the header. Further, non-standard, metadata can be stored as a series of attributes in the vector footprint for each .las tile.



University of Arkansas LiDAR Survey  
HS7-WIO # 20843  
AO Contract # RV 12405-055-00

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**2 GROUND CONTROL SURVEY**

**2.1 GPS Control Network**

The GPS control network consists of six (6) NGS monuments (CARLPORT, K 124, M 110, M 115, P 148 & S 177), four (4) NGS CORS (ARST, ARSP, ARLE & MS25), and one (1) set point (SA 1) established within the south west project boundary. The network acquisition was done from 17 December 2010 through 28 January 2011.

Table 1 below shows the control network input information:

ID	Name	Latitude (m)	Longitude (m)	Elev. (m)	Proj_Order	Dist_Order	Dist_Class
D94890	ARST	33.43 35.52887	91.37 43.73873		A		
D94703	ARSP	33.41 45.77881	91.36 01.95181		A		
D94707	ARLE	34.40 21.44379	92.22 37.98174		A		
E20112	CARLPORT	34.86 16.75620	91.43 40.90371	73.8	1		
E20708	K 124	34.91 45.88825	91.38 16.92292	92.17	0	2	0
E20702	M 110	34.39 27.20806	91.36 51.20806	64.879	1	2	
E20704	M 115	34.22 14	91.21 48	69.803	1	2	
E20707	MS25	34.86 32.29178	90.41 24.99293		A		
E20107	P 148	34.38 36	91.23 33	65.236		1	2
E20105	S 177	34.35 22	91.26 25	63.282		1	2
N/A	SA 1	34.24 23.2	91.54 53.4				

Table 1: University of Arkansas Control Network Input Information.

A graphical representation of the Control Network is provided below in figure 1.

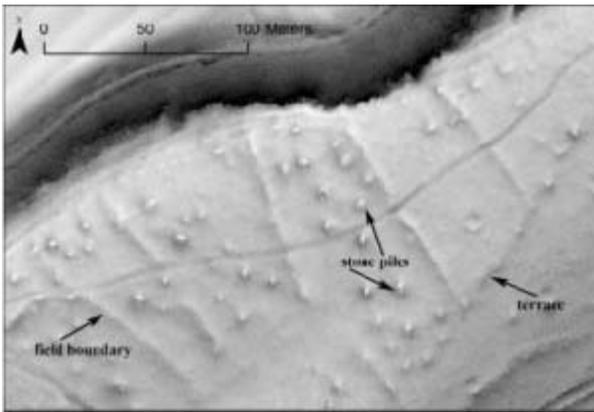
Project level metadata provided by the vendor, Aeroquest, provides important information about the survey.

## laz compression

The ASPRS standard .las format is commonly used for storing ALS data. The compressed .laz format is also useful, particularly for the datasets which are being archived. Data can be converted from .las to .laz (and back) using [LASzip](http://laszip.com).

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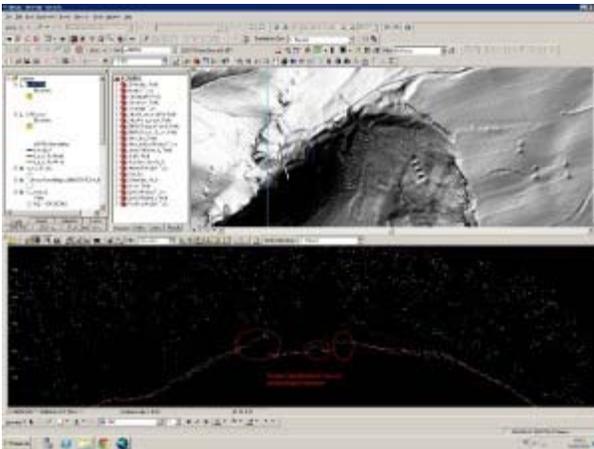
## ALS and Archaeology.



Hillshaded lidar terrain model revealing (undated) remains of field systems now located within the Chailluz Forest, France. ALS Data credit: Region de Franche-Comté / MSHE Ledoux

Airborne Laser Scanning (ALS), or lidar, has been described as one of the most important innovations in data collection and interpretation for archaeology in recent years (Bewley et al. 2005). Certainly, ALS has become an important part of the archaeologists toolkit. First, and perhaps foremost, it has been employed in mapping and prospection surveys in woodland, scrub and open ground. Critically, it may provide the only means of survey -and consequently the collection of archaeological information- in difficult to access areas. Beyond prospection, ALS is now used in research and cultural heritage managements tasks ranging from assessments of the impact of hydrology on site locations, to the calculation of inter-visibility of a network of sites, to the analysis of landforms to create inputs for predictive modeling. The popularity of ALS for studying forested areas, floodplains and rural areas in general has renewed interest in the topic of topographic survey, and further spurred integration with digital technologies and applications. The growing use of ALS in archaeology has raised a number of issues, briefly outlined here.

## Basic Processing and Classification.



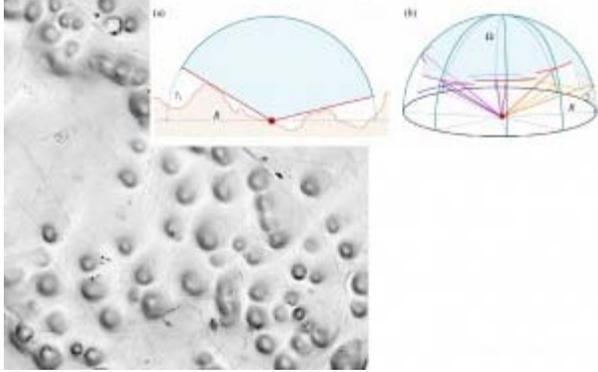
Points incorrectly classified as low vegetation (dark green) which should be terrain (orange).

Archaeological applications demand high quality processing and classification of the ALS data. Because many buried or surface archaeological features are both small scale (in xy) and low relief (in elevation) and are often in woodlands or other heavily vegetated areas, good alignment within the point cloud is necessary to minimize noise, and a good classification is necessary to distinguish between low vegetation and low

relief terrain features which may represent archaeological remains.

## Visualization.

Processing and visualization clearly affect interpretations. There are many possibilities to generate new models and visualizations, and a concurrent possibility of continually tweaking parameters in the hope of 'improving' the model. Archaeologists undertaking a project using visualizations should pose two questions. First, how much information can be retrieved, and with how much effort? Crutchley (Cowley and Opitz 2013) observes that if one model gives 90% of the nominal 'total' information, then the decision not to chase the other 10% may be a practical one. This pragmatic approach avoids the dangers of losing sight of survey objectives in an endless round of data processing and manipulation. However, assessing the cost/benefit and deciding where to stop data manipulation, because a certain approach gives enough information for the task at hand, is not always obvious.



Sky View Factor visualization of karstic terrain. Schematics image credit: Zaksek et al., 2011

Popular 2D visualizations of bare earth DTMs in archaeology include:

- -Classic Hillshades
- -Multi-Directional Hillshades
- -Slope Maps
- -Sky View Factor
- -PCA of multiple Hillshades

Simultaneous viewing of the point cloud, in profile or as a 3D model, alongside the shaded terrain model is common practice. The combined information from multiple views of the same data helps interpreters to understand if a small bump is likely to be a potentially archaeological mound, or built up soil around the base of a particularly large tree, not fully removed by the filtering process.

## Metadata about Visualizations.

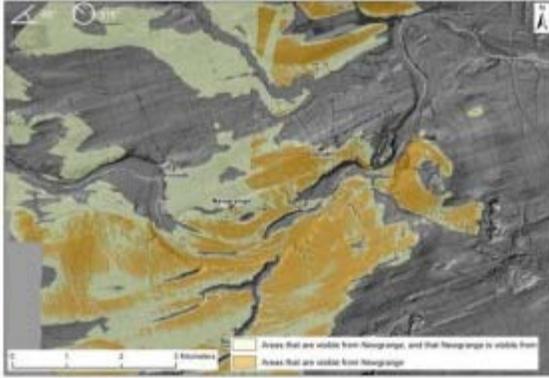
Providing detailed information on how a model and visualization was created is essential for others to understand and evaluate the end product and interpretation. Kokalj et al. (in Cowley and Opitz, 2013) recommend metadata about processing and visualizations as follows:

- -data scanning: scanner type, scanning density, density of a combined dataset, scanning date;
- -data processing: method(s) used, parameter settings, description of the processing goal (e.g. producing a terrain model, removing just the vegetation), elevation model resolution;
- -visualization: method(s) used, parameter settings (e.g. hillshading (Sun elevation and azimuth), LRM (method, distance), SVF (distance, directions));
- -interpretation process: reliability of the results (qualitative if quantitative evaluation is not possible, e.g. low to high, description of each class is recommended).

## Analyses Using lidar DTMs.

The detailed terrain models produced from ALS data are used in archaeological research and cultural resource management as inputs for a number of analyses. These include:

- -Visibility Studies
- -Predictive Modeling
- -Least Cost Path and Cost Surface Modeling
- -Erosion Assessments

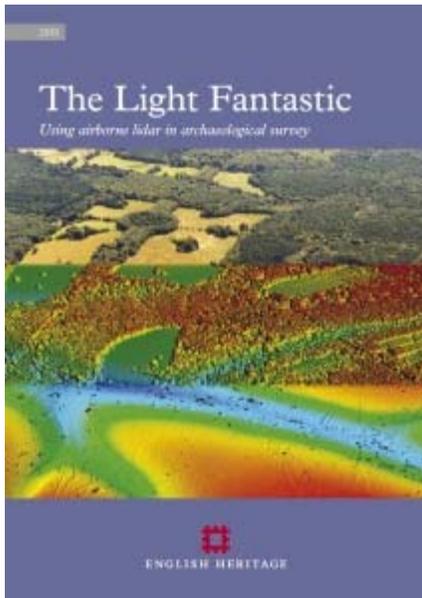


Viewsheds calculated based on the lidar DTM of the Boyne Valley, as observed from Newgrange. Image credit: Opitz and Davis, AARG 2012

## External Resources.



[The ArchaeoLandscapes Project](#) is an EU based project promoting the use of remote sensing and surveying technologies in archaeology. Their website is an excellent resource for both general information and case studies about the use of ALS in archaeology.



[The English Heritage Guide to Airborne Laser Scanning](http://gmvc.cast.uark.edu/scanning/airborne-laser-scanning/als-and-archaeology/feed/) provides good information on the use of ALS in the context of a national cultural heritage management organization.

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