An Introduction to LiDAR for Archaeology
Understanding LiDAR

LiDAR (Light Detection and Ranging) is a remote sensing technique, used for high-resolution survey of landscapes. The technology is based on the use of a laser scanner, mounted on an aircraft. Laser scanners emit pulses of laser light at a rate of many hundreds of pulses per second, and measure the time it takes for the reflection of that pulse to return to the instrument; a GPS is used to plot the coordinates of each measurement. Using this method, powerful computers are able to compute millions of measurements in a dataset called a ‘point cloud’. In turn, this point cloud is then used to make very detailed representations of the ground surface, called ‘digital terrain models’, often referred to as ‘DTMs’.

First Return and Bare Earth

LiDAR data is typically used in two formats, known as the ‘first return’ data and the ‘bare earth’ data. The First Return data is based on the first reflectance of the laser pulse, meaning that the tops of trees, bushes and buildings are incorporated into the terrain model. Bare earth data uses the data reflected back from the ground surface, meaning that tree and bush cover is removed. This is useful for obvious reasons, but in some cases can result in archaeology being ‘stripped off’ too, so that it is important to consider both datasets when looking for archaeology.

Visualising LiDAR data

Hillshades

DTMs are very versatile sources of data. Using mapping software called GIS (geographic information systems), it is possible to cast a simulated light across the landscape to create what is known as a ‘hillshaded’ model. Hillshades are very effective ways of representing topographic relief, as they present the ground surface in a realistic way, meaning that archaeological features like earthworks, banks, walls, ditches, cairns and other features are visible, standing prominent from the ground surface and casting a (virtual) ‘shadow’. The human eye responds well to relief lit in this realistic way, making the 3D data easy to understand and interpret. Standard
An example of first return data (above), and bare earth data (below) for a fort site in Shropshire. Note how LiDAR pulses that have penetrated the tree canopy and vegetation cover to reach the ground can be used to produce a terrain model of the ground surface, effectively ‘removing’ the trees. Using this method, the rampart and ditches of two later prehistoric enclosures are revealed.
Hillshaded LiDAR data, lit from the north west (azimuth 315 degrees) and from an altitude of 30 degrees.

LiDAR DOES:
- Take very accurate measurements of the ground surface
- Record what can be seen (with a line of sight) from the air
- Map topography in 3D, i.e. in X, Y and Z dimensions

LiDAR DOESN’T:
- Penetrate the ground or water (i.e. it will not ‘see’ buried features)
- See ‘through’ trees (it can record the ground beneath tree cover if there are enough gaps between leaves and branches)
- ‘Detect’ archaeology: if nothing shows on the ground surface, LiDAR doesn’t see it!
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Hillshades are the most commonly-used form of LiDAR visualisation.

**Other visualisations**

Realistic hillshades are very effective ways to display LiDAR data, but they have their limitations. When lit from one direction, any features aligned with the source of light can be hidden, since they do not cast any shadow. Similarly, looking at terrain lit from one direction can cause some features to be represented in a misleading way, resulting in false identifications. However, DTMs can be visualised in other, ‘non-realistic’ ways, that allow more features to be visible. Some common visualisations that you might see are:

- **Multi-directional hillshades**
  Like standard hillshades, multi-directional hillshades use simulated lighting to illuminate terrain, but unlike real lighting they combine multiple sources of light, meaning that features are illuminated regardless of how they lie in relation to the light. These hillshades can be strange to look at, since they have no equivalent in the real world, but they are good tools for analysing the landscape.

- **Combined shadings and ‘Swiss-style’ hillshading**
  Combined shadings use a similar technique to High Dynamic Range (HDR) in photography. By combining several ‘strengths’ and directions of shading, dark areas of the terrain are brightened, while bright areas are toned.

The limitations of hillshading from one direction: above, the same area is illuminated from the NW (top left), SE (top right), NE (bottom left) and using combined shadings (bottom right). Note how features are invisible when aligned with the light source direction.
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down - this can reduce the risk of features being missed if they are located in shaded or brightly-lit areas. A variant of this approach is known as the ‘Swiss’ hillshading technique (as it was first developed by cartographers depicting relief in the Swiss Alps), which combines several treatments of the terrain to produce a visualisation that is well lit overall.

Slope

GIS software can analyse terrain data to tell you lots of information that is not visible. One good example which is of use to archaeologists is the degree of slope in a terrain model. Using this technique, the landscape is coloured according to how steep a slope is, meaning that areas of relief are shaded against the background terrain.

Local Relief

Local relief models (often referred to as LRM) use a processing technique whereby the general trend of the local terrain is removed from the terrain data, leaving only the minor, localised ‘lumps and bumps’. This is a very effective way to identify archaeological features, and avoids the limitations of hillshades (which are reliant on light sources). However, LRMs can also introduce data ‘artefacts’, such as gullies and mounds, so they require careful interpretation.

Colour Ramps

Colour ramps are often used when displaying terrain data. Colour ramps simply use a colour palette to display height or other values across a range displayed in the image. Common colour ramps for terrain would go from orange or red at high points, through green to blue and purple in low areas. Other colour ramps can be monochrome, i.e. light green to dark green or black to white. The colours themselves are not standardised and different colours suit different purposes, so it is always important to look at the map key associated with the image, in order to interpret the map correctly. The key should label the colour ramp used with the range of values present in the map.

A colour ramp, filtering the terrain model by elevation value in metres above sea level (Ordnance Datum).

An example of a local relief model, showing minor variations in local topography.
Analytical hillshading: the image above is lit from a single direction (NW), the image below combines 16 shading directions into one image. Many more features become visible when the lighting directions are combined.
Non-Archaeology

Before beginning to look for archaeology in a LiDAR dataset it is important to be able to recognise ‘red herrings’. There are several reasons why misleading features can appear in LiDAR data, and it is important to be able to recognise them. The best way to avoid being misled by data artefacts is to cross check the LiDAR data against other sources, like aerial imagery.

A selection of data artefacts is included below:

Swathe Lines

Swathe lines are often present in surface models- i.e. terrain models produced from the first response of the LiDAR laser pulse- and can also be visible in bare earth models. They are caused by areas of overlap between lines of flight by the aircraft during data acquisition, which have caused slight mis-matches in the point cloud.

Water noise

Water tends to cause a messy noise to appear in LiDAR data. While some laser light is reflected, some penetrates shallow water. This can typically appear as noisy, messy areas in LiDAR data.

Coarse terrain under vegetation

Since LiDAR can only produce a model of the ground surface beneath trees and other vegetation if a line of sight is possible, in some areas this can mean that only a small number of measurements have been taken on the ground surface. In areas like dense forestry or gorse bushes, this can show up as very ‘bumpy’ ground, since only a coarse terrain model can be built.

Non-Archaeology: Misleading Features

Another reason for misinterpreting LiDAR can be the presence of modern farming features or structures that closely resemble real archaeological sites. These include things like drainage ditches, field dykes, sheep folds and other enclosures. Common ‘red herrings’ are the circular traces left by cattle feeders: when the feeders are moved, the circular depressions caused by animals trampling around the feeder are often left behind, closely resembling archaeology! As always, the best way to avoid being misled is to cross check the feature against aerial imagery or other mapping sources.
The image above shows changes in vegetation and ground cover that are represented in the LiDAR data, below. However, a swathe line is present on the left hand side of the LiDAR image, and does not equate to a real world feature. Imagery: (C) ESRI.
Identifying Archaeology

The archaeological field monuments of Caithness come in a wide range of shapes, sizes and types, and relate to the earliest farming communities of the Neolithic through to the modern period. There are no ‘rules’ that stipulate what archaeological remains will look like, but some important general considerations are as follows:

- **Condition**: what might have happened to the site since abandonment? Could this feature be a fragment of something bigger?
- **Modification**: Could the site have been re-used as something else?
- **Later activity**: does everything visible relate to the same period, or could some parts be earlier than others? Do you have more than one site?
- **Modern land use**: could anything in the modern landscape be obscuring the archaeological traces visible, or causing them to appear to be something other than they are?
- **Topography**: how does the site relate to its immediate surroundings? Does your interpretation make sense in the local context (although don’t place too much weight on this!).

Consider Geomorphology

It is important to have a feeling for the bedrock geology and geomorphology of your study area when looking for archaeology. In Caithness, for example, the bedrock is mainly Caithness flagstone, which results in a very tabular form to rock outcrops. The principal movement of the ice sheet during the last glaciation was outwards, north and east towards the sea from the high ground inland; the traces of this movement are visible on the sides of hills and knolls across the study area. Where you see linear features cutting across the natural ice movement direction, it is worth considering whether these are the result of human activity.

Some Typical Caithness Site Types

**Cairns**

Chambered cairns date from the Neolithic and, in Caithness, come in a variety of forms. The best preserved examples often have a trapezoidal shape with an elongated ‘tail’ of cairn material adjoining the central chamber area. However, some cairns are circular, while others are very irregular.

**Hut Circles**

Hut circles are the remains of prehistoric roundhouses. They were built in Scotland from the later Neolithic through to the early medieval period, though most of the examples excavated produce Bronze and Iron Age dates. They typically comprise a circular bank of earth and stone, between 7 and 15m in diameter, though more typically in the 9 to 11m range. Evidence of an entrance may or may not be visible, and they are often found in groups, sometimes in association with clearance cairns.

**Clearance cairns and cairnfields**

Clearance cairns are found across the British landscape in a wide range of forms. Prehistoric cairnfields are areas where early farming groups cleared the land of stones for agriculture, piling them into small cairns, usually a few metres across. Cairnfields often survive in marginal land, where modern agriculture has not obliterated them, and they are often associated with hut-circle groups.
Burnt mounds mostly relate to prehistoric activity, with most excavated examples producing dates in the Bronze Age. They are mostly thought to be cooking sites, and are the result of heating stones to high temperatures for boiling water. When the stones shatter, they are heaped into mounds around the central activity area. Burnt mounds often have a characteristic crescentic shape, and are typically found next to water, such as small streams, rivers or lochs.

Ramparts and defences
Later prehistoric sites were often defined by enclosing rampart defences, visible as earth and stone mounds which often follow the contours of a hill or cut off a promontory of land. In Caithness they are often associated with brochs, though there are also a small number of prehistoric forts that may have Bronze Age origins.

Brochs
Brochs are typical of the Caithness Iron Age, and there are many visible across the county. Most are unexcavated and appear only as large, roughly circular mounds of stone. Sometimes broch site have a characteristic ‘bowl’ in the interior, indicating the internal space now filled with rubble. In other cases, broch mounds can be conical in shape, where the stone walls surrounding the rubble collapse of the structure have been robbed and removed, leaving only a grass-covered stony mound.

Field boundaries
Being very generic, field boundaries are often difficult to date, and prehistoric field divisions can easily be mistaken for those of much later centuries. In some cases, it is possible to suggest that field boundaries might belong to the prehistoric period, such as where they are demonstrably associated with prehistoric buildings. However, this is difficult to do with certainty!

Medieval and later farmsteads
From the medieval period and onwards in northern Scotland, oblong and rectangular buildings were the standard settlement form. Where preservation is poor, it is virtually impossible to determine the date of rectangular buildings in Caithness, and they are often referred to as ‘MoLRS’ sites, meaning ‘medieval or later rural settlements’ - a deliberately catch-all term. Stone longhouses were in use well into the modern period, often on sites that have been in use for long periods of time. In some cases, it is possible to identify a succession of longhouses on the same site, visible in the LiDAR data.

Rig and furrow agriculture
One of the most characteristic features of the historic landscape in rural Scotland, rig and furrow agriculture is found in abundance in Caithness. Rigs, or ‘lazy beds’ are a technique designed to increase soil depth and improve drainage for crops. They can be hand dug, or formed by horse-drawn ploughs. Where the latter is the case, they can have a characteristic reverse-S shaped form- caused by the horse turning at the end of each furrow- and are sometimes called ‘reverse-S shaped fields’. Rig and furrow comes in a very wide range of forms, however; there is no reliable way to date it by its form, though it is often possible to be confident in the broad date through association with buildings and other features.
Remains of rig-and-furrow agriculture visible in a multi-directional hillshade image.