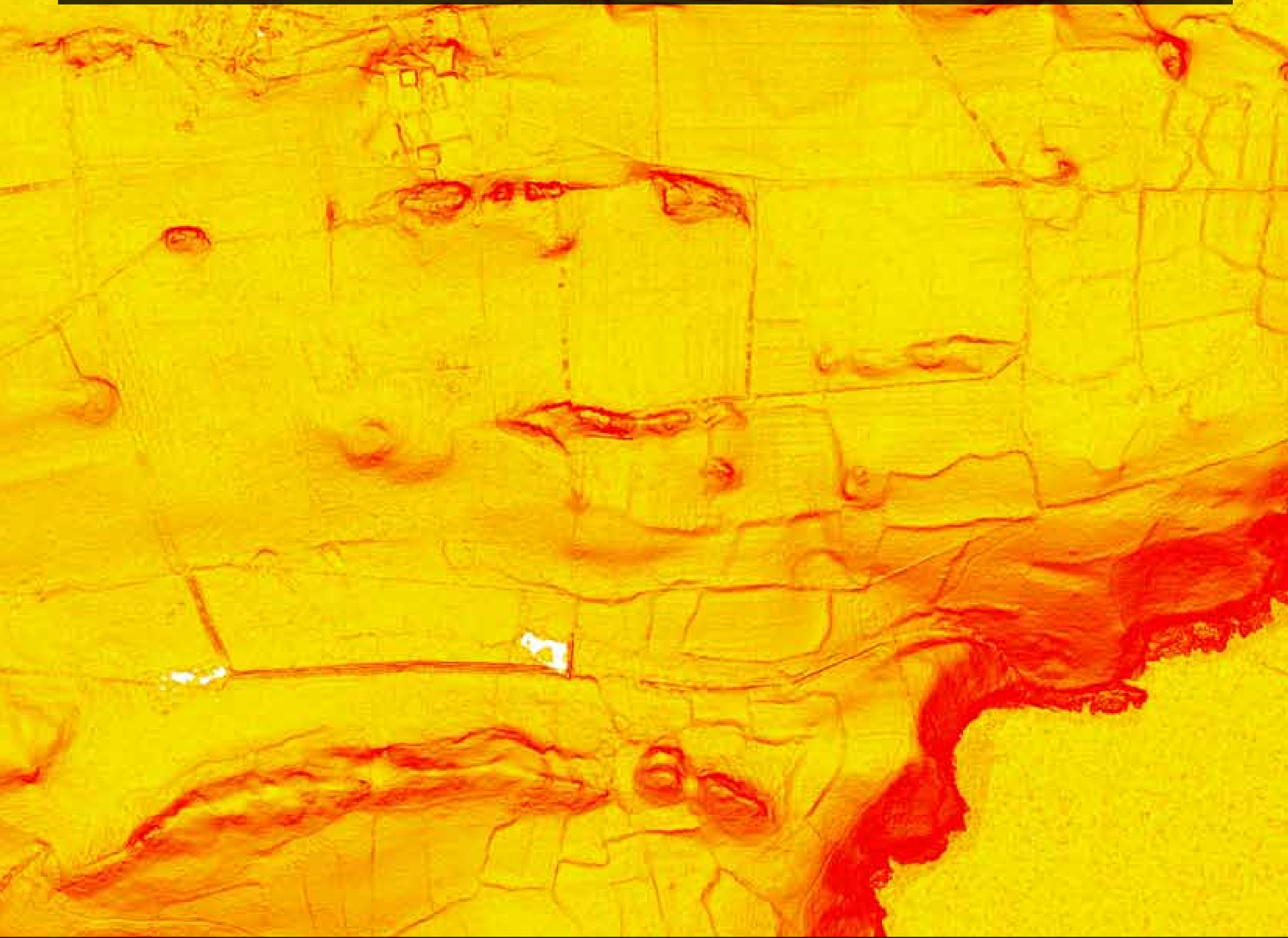
Processing and Working with LiDAR Data in ArcGIS:

A Practical Guide for Archaeologists

By Oliver Davis



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Published in 2012 by The Royal Commission on the
Ancient and Historical Monuments of Wales.

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Royal Commission on the Ancient and Historical Monuments of Wales

Plas Crug, Aberystwyth, Cymru/Wales, SY23 1NJ

Ffacs/Fax: 01970 627701
Ffôn / Telephone: 01970 621200
e-bost: chc.cymru@cbhc.gov.uk
e-mail: nmr.wales@rcahmw.gov.uk
Gwefan: www.cbhc.gov.uk
Website: www.rcahmw.gov.uk

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Cover: LiDAR visualisation of Skomer Island, Pembrokeshire (© Crown: All rights reserved. Environment Agency. LiDAR view generated by RCAHMW).

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1.0 SUMMARY

These notes provide basic step-by-step instructions for archaeologists intending to use, analyse and interpret airborne LiDAR data. The aim is to provide an explanation of, and guide to, the basic technique of creating simple visualisations, such as a hillshade, from raw LiDAR data tiles (ASCII files) in ArcGIS 10. The guidelines are also applicable for ArcGIS 9 users as the processing follows the same general structure.

2.0 PART 1 – WHAT IS LIDAR AND HOW IS IT COLLECTED?

2.1 What is LiDAR?

Airborne Light Detection and Ranging (LiDAR) is a method of remote sensing that obtains three-dimensional data points by using a laser mounted on an aircraft. Sometimes known as Airborne Laser Scanning (ALS), it was originally developed for military purposes in the 1970s and 1980s. It was first used as a means of finding submarines, but it was subsequently turned to terrestrial use to produce highly detailed terrain models. In the UK the civilian use of LiDAR was pioneered by the Environment Agency who, in the mid-1990s, began using it as a tool to produce cost-effective terrain maps in order to assess flood risk. Its application for the identification of archaeological features, however, has only been fully realised in the last 10 years as high-resolution datasets have become available.

Airborne LiDAR provides the ability to acquire detailed three-dimensional data over a large area in a relatively short period of time. It is a powerful tool for identifying and mapping features with a topographic expression, but is best used as part of a remote sensing toolkit that encompasses aerial photography and ground-based approaches to landscape archaeology.

2.2 How is LiDAR data collected?

In order to collect data the LiDAR sensor is mounted below an aircraft where it emits short infrared laser pulses towards the earth's surface, fan-shaped across the flight path (Figure 1). Each pulse results in multiple echoes or 'returns'. The first return will usually be received from the tops of trees and vegetation, but as the laser penetrates the canopy further returns are received from branches and understorey. Typically, the last return is received from the ground surface. As the aeroplane moves forward the position of each return, or point, can be calculated using a satellite navigation system in tandem with a fixed ground-base system, while the pitch, roll and yaw of the aircraft is recorded by an inertial measurement unit to increase accuracy. Each point therefore has a set of x, y, and z coordinates to reflect its position and elevation.

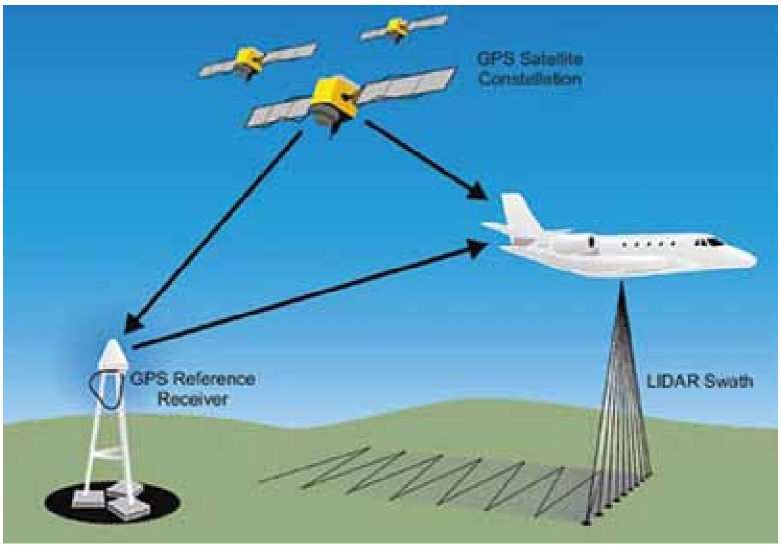


Figure 1: Principles of LiDAR collection (after Holden et al. 2002).

A LiDAR survey produces thousands of such points, which when imported into a Geographic Information System (GIS) produces a point cloud: literally a cloud of points. The point cloud can then be processed, using computer algorithms, to remove all but the first and last returns. The remaining data can then be used to create a Digital Surface Model (DSM) and Digital Terrain Model (DTM) for visualisation and interpretation.

A DSM is a model of the surface of the earth, generated from first return points, which includes all the features on it such as vegetation and buildings (Figure 2), whereas a DTM is a 'bare-earth' model, generated from last return points, with vegetation and buildings (and sometimes archaeological features) stripped away (Figure 3). A DTM is particularly useful for seeing the ground surface beneath high vegetation.

The higher the density of measured points per square metre (resolution) the greater the clarity and detail of archaeological features. Generally, 2 metre resolution data are inadequate for recording many archaeological features. The basic minimum is 1 metre resolution, but typically, it is recommended that two hits per square metre gridded to 0.5 metre ground resolution are required for recording the majority of archaeological features, particularly in woodland. It is possible to collect more points per metre to obtain greater resolution, but this comes at a much greater cost.

Clearly, one of the key areas for the application of LiDAR is in wooded environments, but it is also an extremely useful tool in extensive upland landscapes, where it can be a fast and cost-effective means of mapping topographic features.

Figure 2: Digital surface model (DSM) of Caerau Camp, Cardiff, showing the distinctive triangular interior of the hillfort set amongst houses and trees and buildings (© Crown: All rights reserved. Environment Agency, 100026380, 2011, LD2012_01_06. Funded by the Royal Commission on the Ancient and Historic Monuments of Wales, Cadw, Welsh Government, and National Museum Wales. LiDAR view generated by RCAHMW).

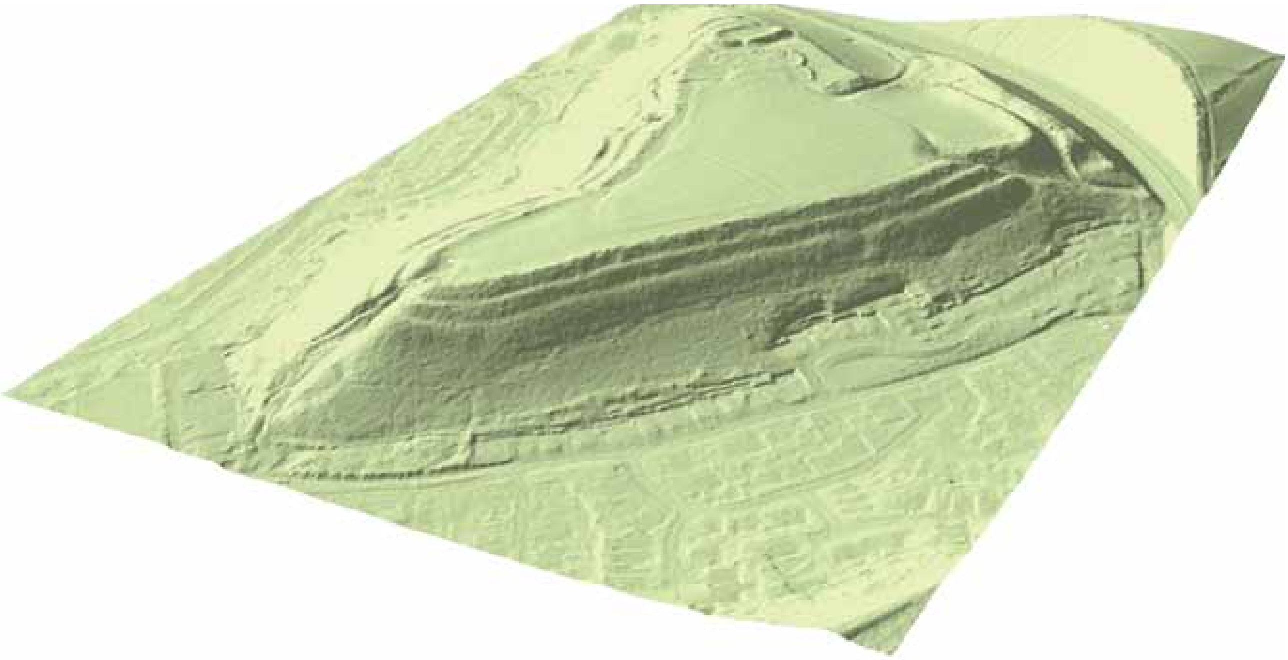


Figure 3: 'Bare earth' digital terrain model (DTM), with houses and trees stripped away reveals the magnificent sculpted ramparts and ditches (© Crown: All rights reserved. *Environment Agency, 100026380, 2011, LD2012_01_07. Funded by the Royal Commission on the Ancient and Historic Monuments of Wales, Cadw, Welsh Government, and National Museum Wales. LiDAR view generated by RCAHMW).*

2.3 Where can LiDAR data be obtained?

A number of commercial companies in the UK regularly collect LiDAR data and are able to supply archived survey data. However, off-the-shelf archived data may neither have been collected at a sufficiently high resolution, nor carried out at a suitable time of year (i.e. leaf-off conditions), in which case it may be necessary to commission a new survey. This guide illustrates standard methods for working with Environment Agency ASCII files, but other datasets are available.

3.0 PART 2 – WORKING WITH LIDAR DATA

Requirements for this guide:

Software: ESRI ArcGIS 10.
Applications: ArcMap, ArcScene, ArcCatalog, ArcToolbox.
Extensions: 3D Analyst, Spatial Analyst.

3.1 Processing raw LiDAR data files

LiDAR data is usually supplied in ASCII file format on a data CD. It is likely that you will receive two folders from your supplier: one that contains DSM data (sometimes pre-fixed D_ASCII) and one that contains DTM data (sometimes pre-fixed V_ASCII). Both will need to be converted to Raster format to be viewed in ArcMap.

3.1.1 File and folder management

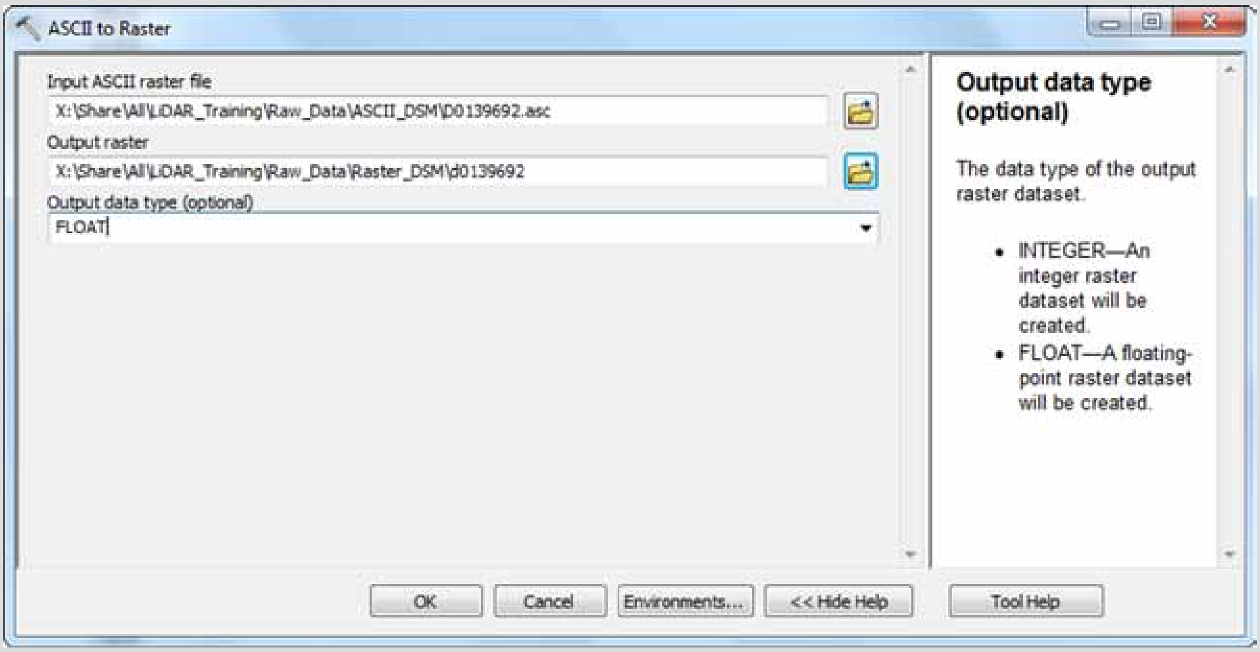
It is best at the outset to create and re-name the files and folders that you are going to be using:

1. Create a folder called LiDAR_data_ProjectXYZ into which all your raw data and working data will be placed.
2. Make a copy of the D_ASCII and V_ASCII folders from the CD and move them into a new folder called Raw_data within the folder LiDAR_data_ProjectXYZ.
3. Re-name the D_ASCII folder ASCII_DSM and the V_ASCII folder ASCII_DTM.
4. Re-name the files in these folders by their OS 1km grid square (e.g. ST8896).
5. Create two new folders in Raw_data called Raster_DSM and Raster_DTM – these will be where the converted ASCII files will be saved.

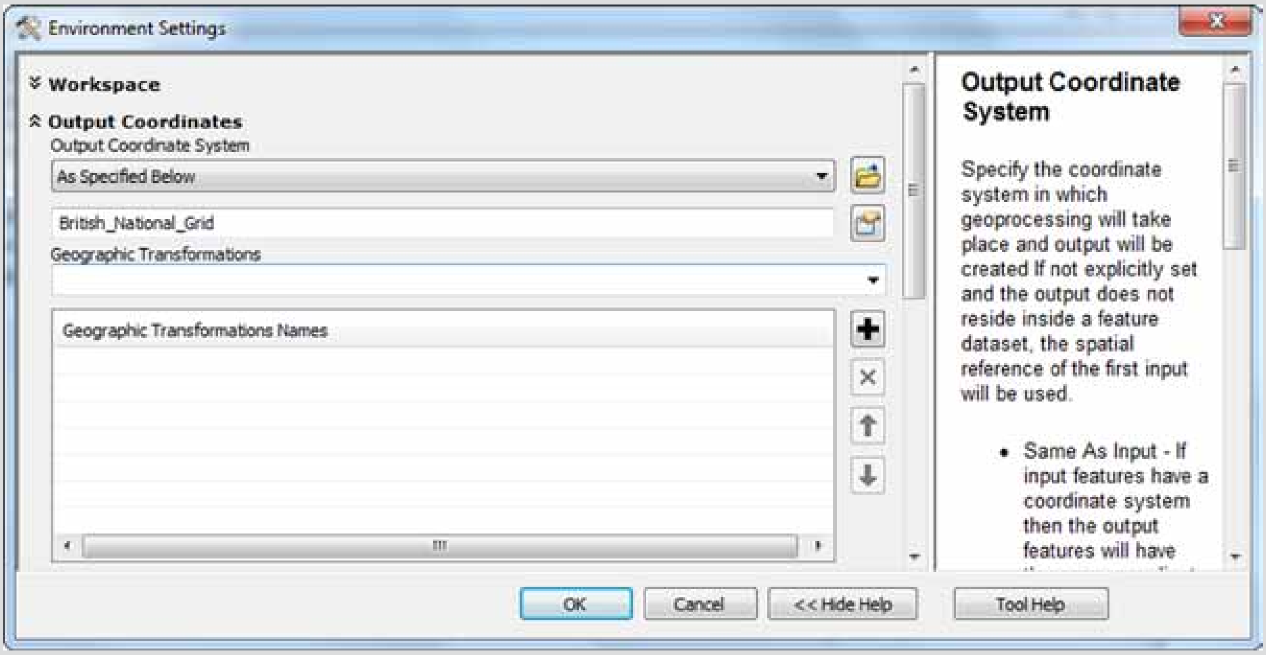
3.1.2 Converting ASCII to Raster

You now need to convert the ACSII files to Raster format so that you can work with them in the GIS:

1. Open up a blank ArcMap document and then open ArcToolbox.
2. Select Conversion Tools – To Raster – ASCII to Raster.
3. In the pop-up box select the 'Input ASCII raster file' you want to convert from the ASCII DSM or ASCII_DTM folders.
4. In 'Output raster' select the location and file name where you want the raster file to go (this should be either the Raster_DSM or RASTER_DTM folder you created earlier). The file name should be the same as the input file.
5. Output data type – select Float (this is important because if you choose 'Integer' here, the raster dataset will have a 'stepped' effect).



6. Environments – make sure output coordinates are selected as British National Grid.



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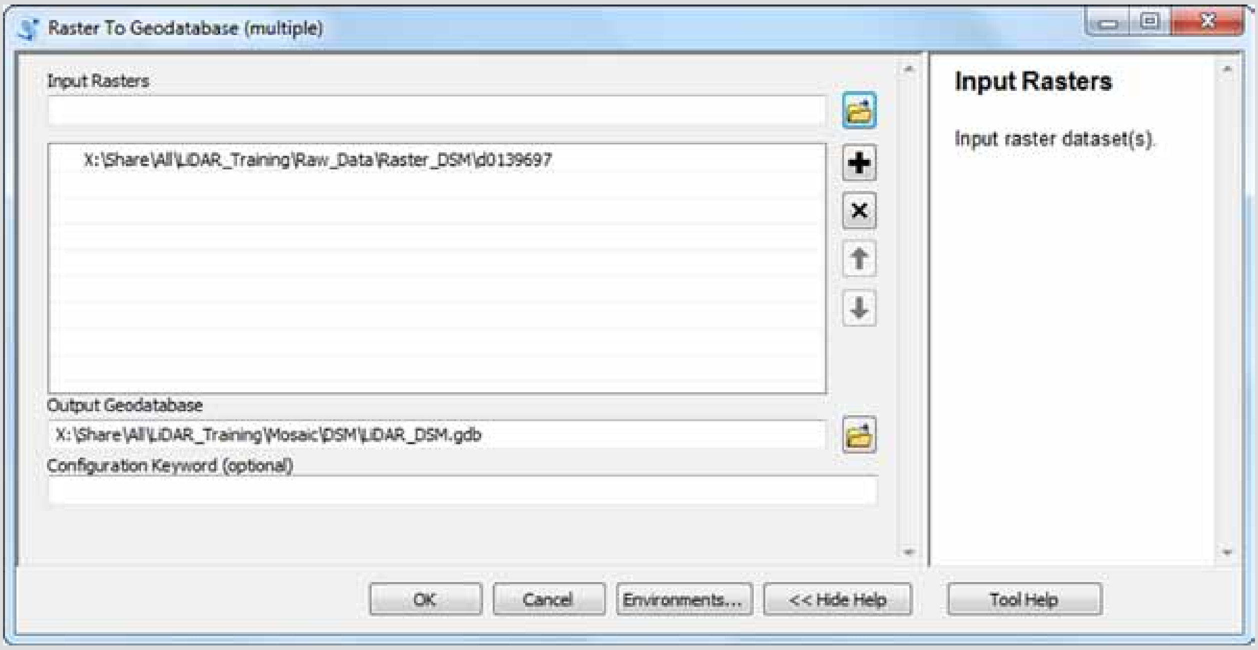
7. Press OK and repeat until all ASCII files have been converted to Raster.

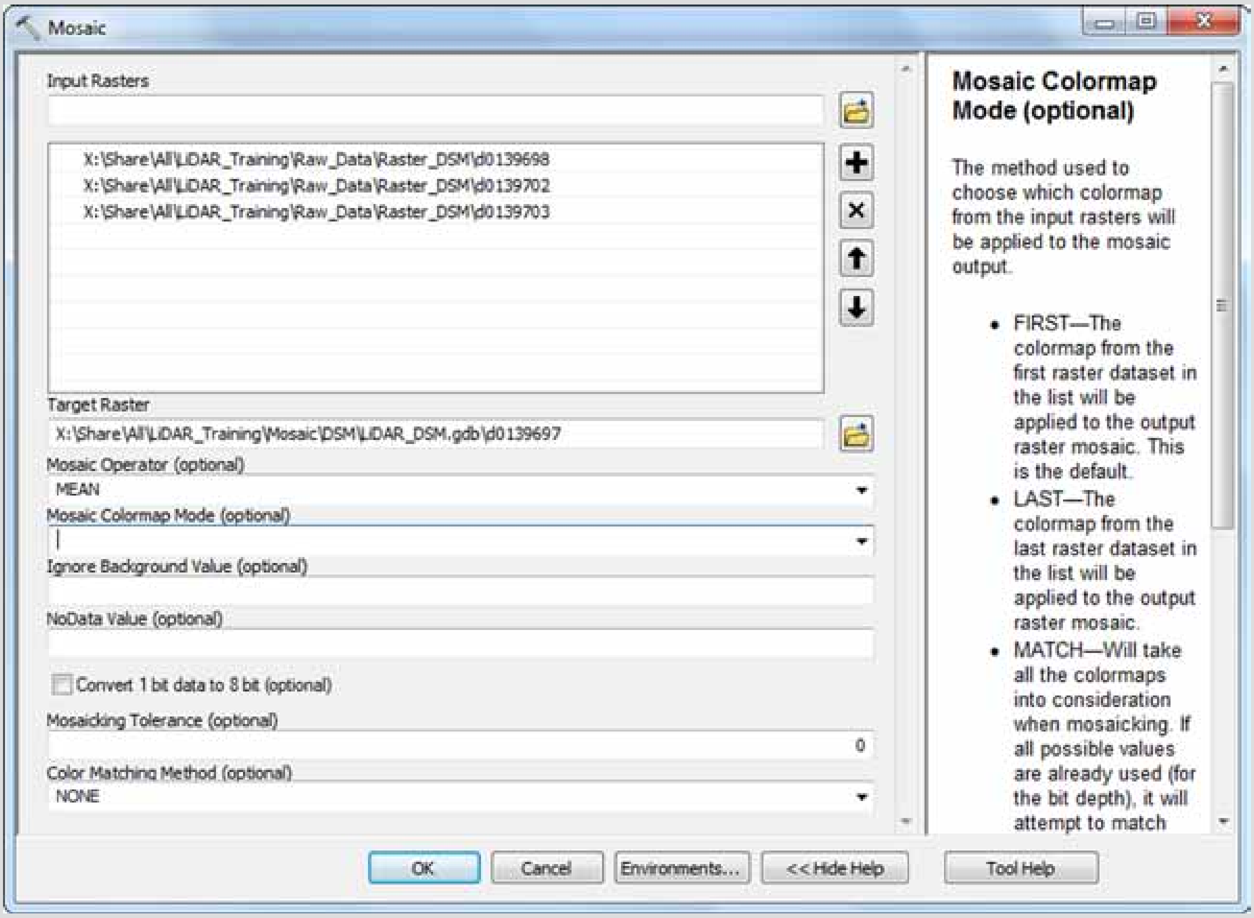
3.1.3 Creating a mosaic

You now need to link all the Raster files together into a single mosaic from which you can create visualisations from the LiDAR data:

1. Open up ArcCatalog and navigate to the folder LiDAR_data_ProjectXYZ.
2. Within the folder LiDAR_data_ProjectXYZ create a new folder called Mosaic.
3. Within the folder Mosaic, create two new folders called DSM and DTM.
4. Within the DSM folder, right click, and select New – File geodatabase, and name it ProjectXYZ_DSM.
5. Double click on the new geodatabase you've created – you now need to import a file to mosaic all the others to.
6. Within the geodatabase, right click – Import – Raster dataset.
7. In the pop-up box, choose an Input Raster from your Raster_DSM folder (it doesn't matter which file), making sure the Environments are set to British National Grid.



8. Once this file has been imported into the geodatabase you now need to select the others to mosaic it to.
9. Within the geodatabase, right click on Raster – Load – Load data.
10. In the pop-up box, in the ‘Input Raster’ box select the Rasters you want to mosaic together (excluding the one you’ve just imported).
11. In ‘Target Raster’, make sure the Raster you originally imported is selected.
12. Make sure that ‘Mosaic Operator = Mean; and Mosaic Colourmap Mode = Match.

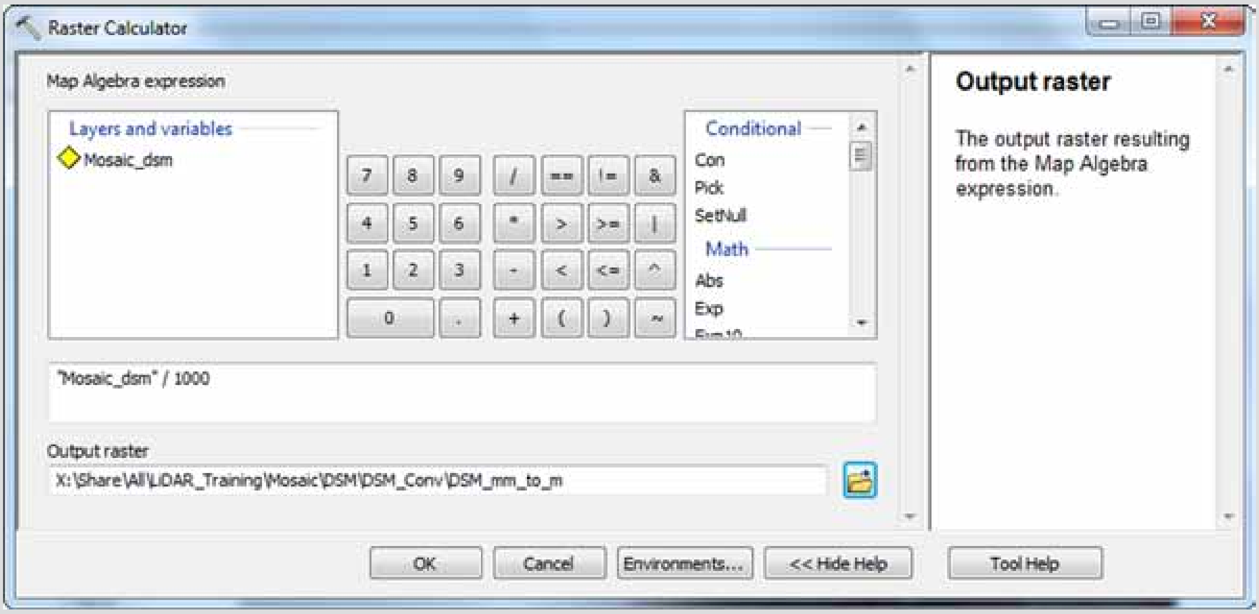


13. Make sure output coordinates (in Environments) are set to British National Grid then hit ‘OK’.
14. You now have a DSM Mosaic – repeat process for DTM.

3.1.4 Converting pixel values

Raw data are often supplied with height values in millimetres (if so it will be necessary to convert these to metres) while archived data height values will normally be in metres. In ArcMap, use the ‘identify’ tool to check some spot heights by clicking on your mosaic. If the ‘pixel value’ (i.e. height) is broadly what you expect for the specific landscape then no calculation is required – go to 3.2. However, if the ‘pixel values’ given are exceptionally high (e.g. 100,000 for a landscape with a height of 100 metres), then the data will need to be converted:

1. In ArcCatalog, navigate to the folder Mosaic and go into the DSM folder.
2. Within DSM, create a new folder called ‘DSM_Conv’.
3. Now open up a blank ArcMap document and add the Mosaic_DSM dataset as a layer.
4. Open up ArcToolbox and select: Spatial analyst tools – Map algebra – Raster calculator.
5. In the pop-up box, double click on the Mosaic_DSM layer and enter the equation ‘/1000’.
6. Select location (DSM_Conv folder) and name of output raster (DSM_mm_to_m).

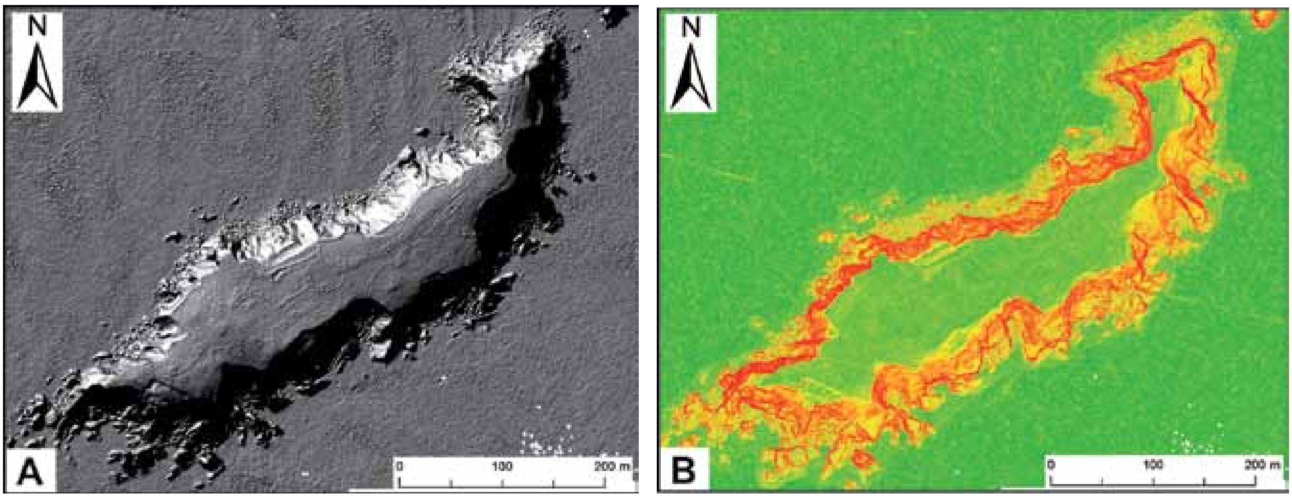


7. Make sure output coordinates (in Environments) are set to British National Grid then hit ‘OK’.

3.2 Visualising LiDAR data

Creating visual models from LiDAR data is crucial for characterising relief features. Depending on how the data is processed, different models can provide different visualisations of relief. There are a wide variety of different analytical models and each have benefits and drawbacks for identifying archaeological features – some are better at picking out features in low relief topography, others for defining steeply sloping earthworks. Therefore, it is crucial when analysing data to create multiple models to ensure that all archaeological features can be identified.

These guidance notes provide information for the creation of three visualisations – a hillshade, a slope model and a local relief model. The hillshade is by far the most common visualisation of archaeological landscapes, with earthworks highlighted by a directional light-source. However, both slope and local relief models are particularly effective for comparing and contrasting complex features and revealing complementary information (Figure 4).



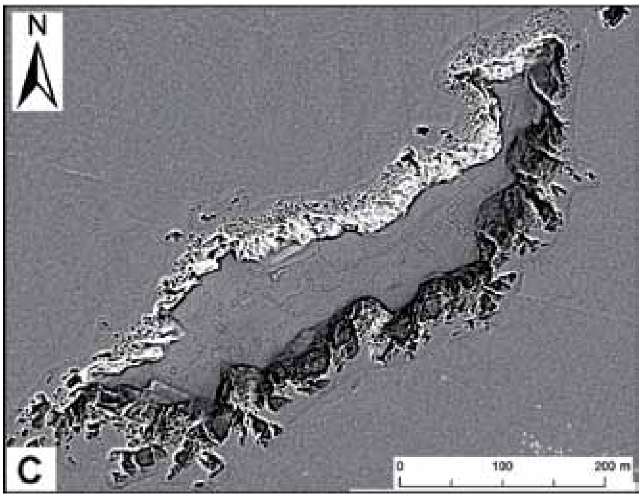


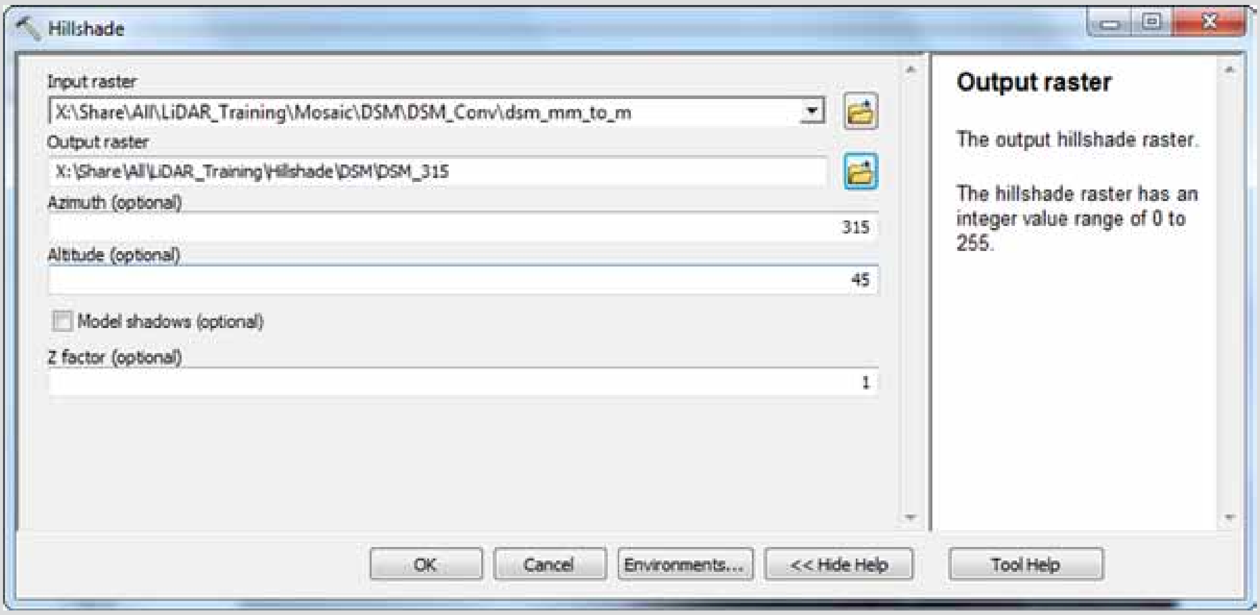
Figure 4: A comparison of different models of the same data for the early medieval settlement on Gateholm islet, Pembrokeshire: A is a DSM hillshade; B is a slope model; C is a local relief model. Note how the local relief model clarifies the plan of the settlement features, some of which are barely discernable from the hillshade (© Crown: All rights reserved. Environment Agency. LiDAR views generated by RCAHMW).

3.2.1 Creating a hillshade model

The most basic model is the hillshade. This is where each cell or pixel is given a value (shading) based upon a hypothetical lightsource. Relief is directly illuminated which makes it possible to intuitively recognise features. Hillshaded visualizations are quite effective for earthwork features with well-defined edges, where the detrimental impact of single azimuth shading is largely overcome and the character of the earthworks effectively represented.

To create a hillshade model:

1. In ArcToolbox, select: 3D Analyst tools – Raster surface – Hillshade.
2. In the pop-up box – Input Raster = DSM_mm_to_m.
3. Output Raster – Select location (create folder called Hillshade within the folder LiDAR_data_ProjectXYZ) and name of output raster (usually suffixed with Azimuth – e.g. DSM_315).



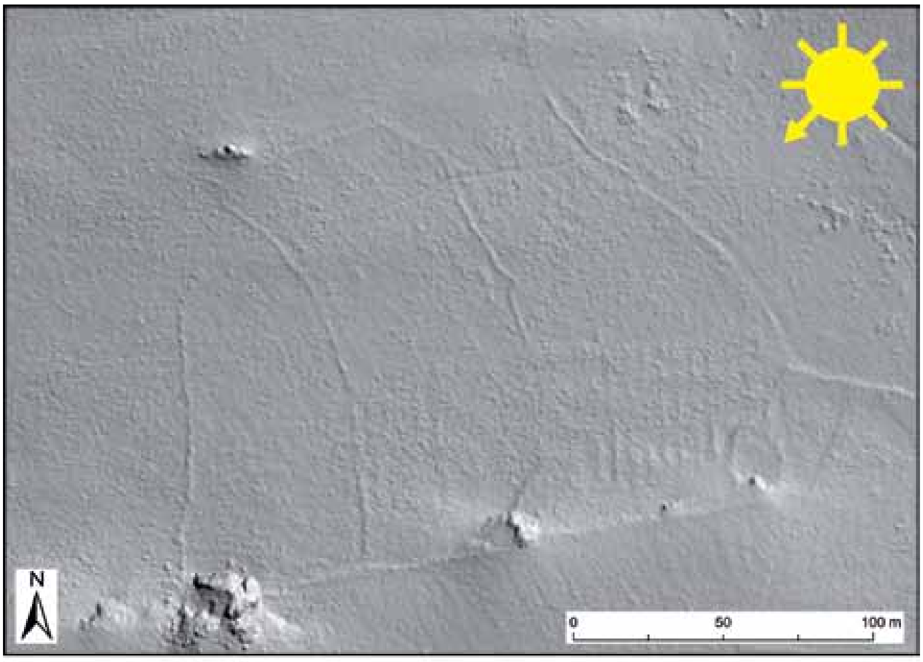
4. Azimuth = 315, Altitude = 45, Z Factor = 1 (these are standard, but it is worth creating more hillshades at different Azimuths, which often reveals different features).

5. Make sure output coordinates (in Environments) are set to British National Grid then hit 'OK'.

6. You now have a DSM hillshade – repeat process for DTM.

7. Save your ArcMap document.

The hillshade has several drawbacks. The most critical are its inability to represent linear objects that lie parallel to the direction of the light source and saturation of shadow areas. One way to overcome direct illumination is to create multiple hillshaded models with the sun at different angles, saving each of these as a separate layer in the GIS that can be switched on and off for the purposes of comparison (Figure 5).



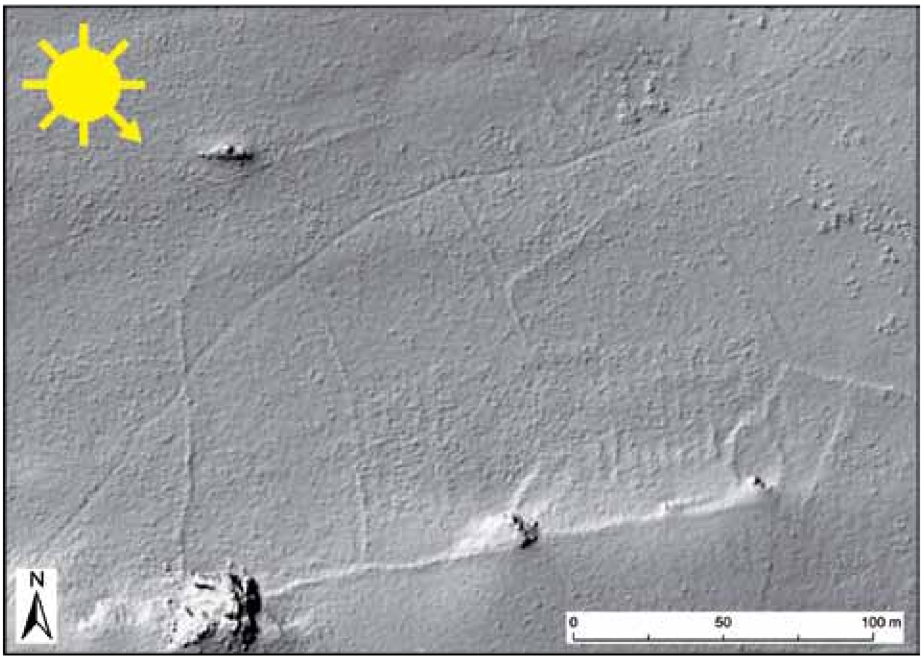


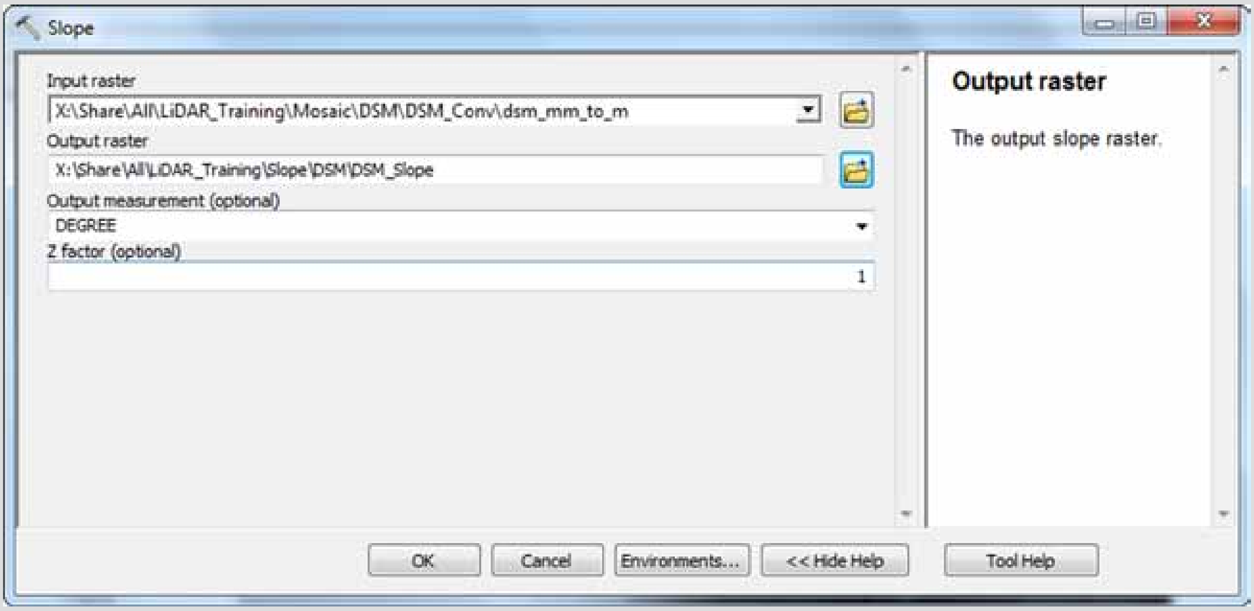
Figure 5: Two hillshades of the same landscape, with the light-source set from different angles, reveals field boundaries hidden to single direction illumination (© Crown: All rights reserved. Environment Agency. LiDAR views generated by RCAHMW).

3.2.2 Creating a slope model

Whereas hillshades calculate the shading of each cell based upon a hypothetical light-source, slope models calculate the slope severity value for each cell. Visualization of slope severity is, predictably, effective for earthworks with steeply sloping sides and provides useful insight into the character of the earthworks, but is markedly less successful in identifying the gently sloping earthworks of, for instance, ridge and furrow.

To create a slope model:

1. In ArcToolbox, select: 3D Analyst – Raster Surface – Slope.
2. In the pop-up box – Input Raster = DTM_mm_to_m.
3. Output Raster – Select location (create folder called Slope within the folder LiDAR_data_ProjectXYZ) and name of output raster (e.g. DTM_Slope).
4. Output Measurement = Degree; Z Factor = 1.



5. Make sure output coordinates (in Environments) are set to British National Grid then hit ‘OK’.

You now need to change the symbology to ‘stretched’ rather than classified:

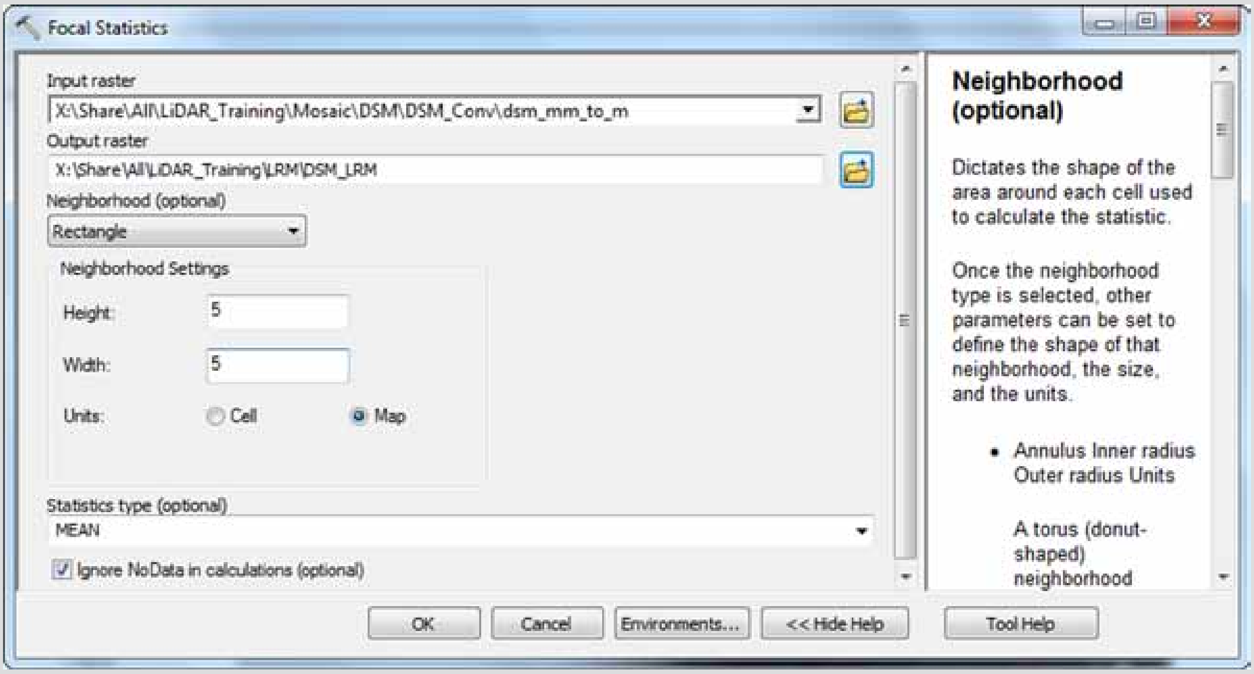
6. Right click on layer and select properties.
7. Under the Symbology tab, click on ‘stretched’ and choose a suitable colour ramp.
8. Click OK.
9. You now have a DTM slope model (a slope model should not be created from a DSM).

3.2.3 Local relief modelling

Local relief models (LRMs), developed by Hesse (2010), attempt to mitigate the masking effect of natural topographic variation on archaeological earthworks through the creation of a 'difference model' by subtracting the DTM from the DSM. This results in a new representation of relief containing only the archaeological earthworks, and is particularly effective in low-relief landscapes. The technique clearly identifies positive and negative features, but subtleties are lost as high-magnitude features mask lower magnitude earthworks.

To derive the LRM or 'difference map' in ArcGIS:

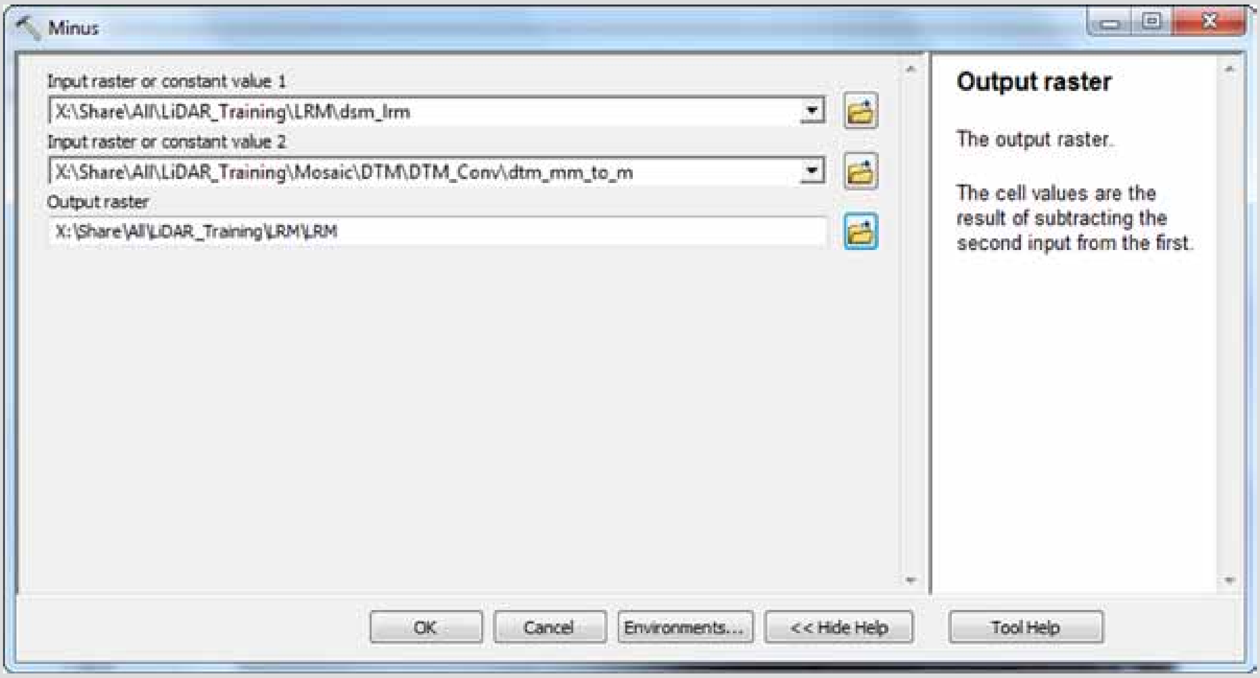
1. In ArcToolbox, select: Spatial Analyst Tools – Neighbourhood – Focal Statistics.
2. Input raster = DSM_mm_to_m.
3. Output raster = Select location (create folder called LRM within the folder LiDAR_data_ProjectXYZ) and name of output raster (e.g. DSM_LRM).
4. Change Units to 'Map' and set the height and width to your decided resolution – you may have to play around with this to see what works best, e.g., 5 metre x 5 metre; 7 metre x 7 metre etc. This smooths your model.



5. Make sure output coordinates (in Environments) are set to British National Grid then hit 'OK'.

Now you have to subtract the outputted raster from the original raster:

6. In ArcToolbox, select: Spatial Analyst – Math – Minus.
7. Input raster 1 = the raster you just created (DSM_LRM).
8. Input raster 2 = DTM_mm_to_m.
9. Output raster = Select location (within the LRM folder in LiDAR_data_ProjectXYZ) and name of output raster (e.g. LRM).



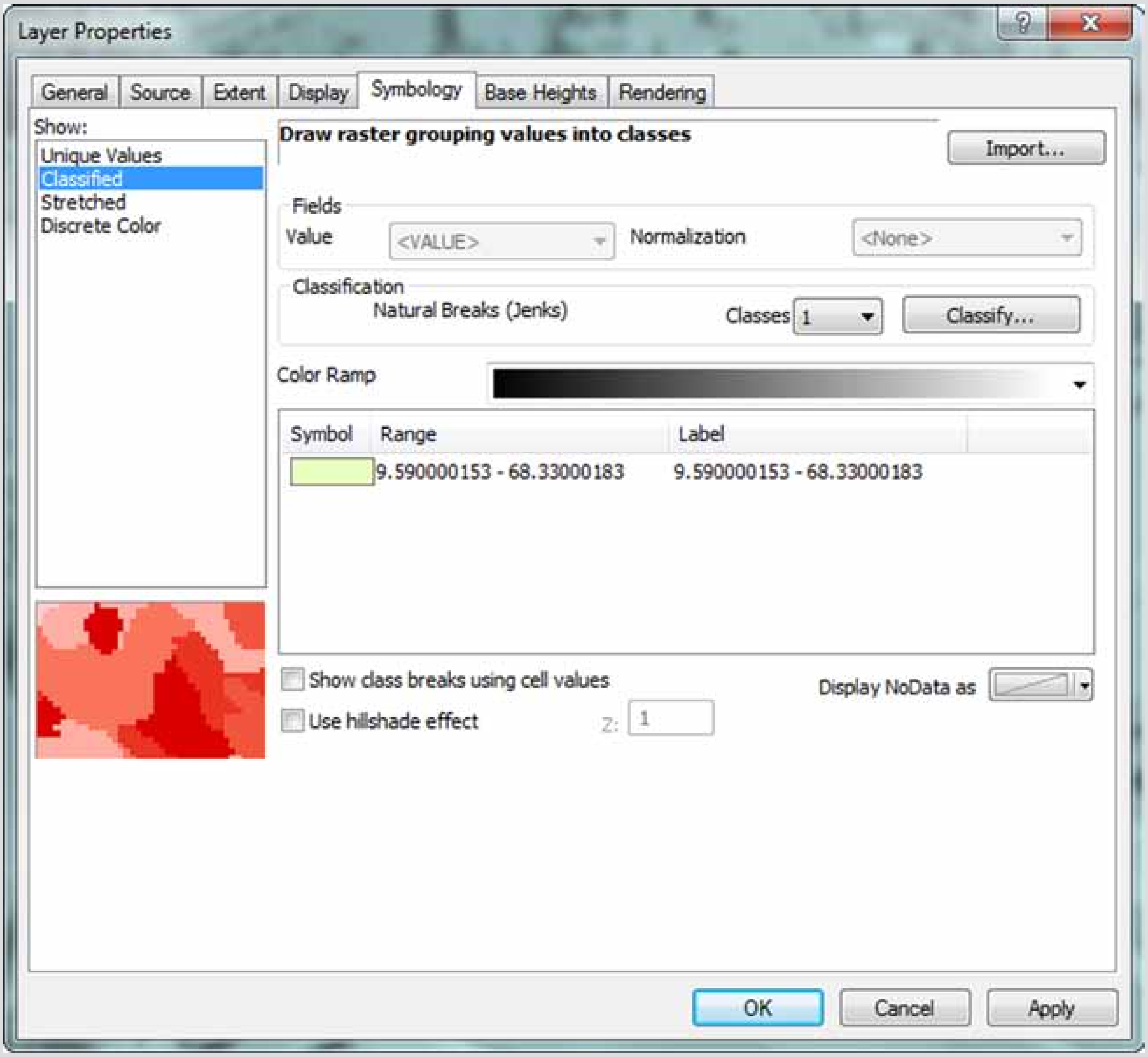
10. Make sure output coordinates (in Environments) are set to British National Grid then hit 'OK'.
11. You now have a LRM.

3.3 Creating 3D visualisations

To create visualisations and animations of the data in 3D for publication or presentation you will need to use ArcScene. Remember to save your ArcScene document regularly as the considerable processing power required to animate 3D scenes can cause your application to freeze or crash.

3.3.1 Creating a 3D surface from LiDAR data

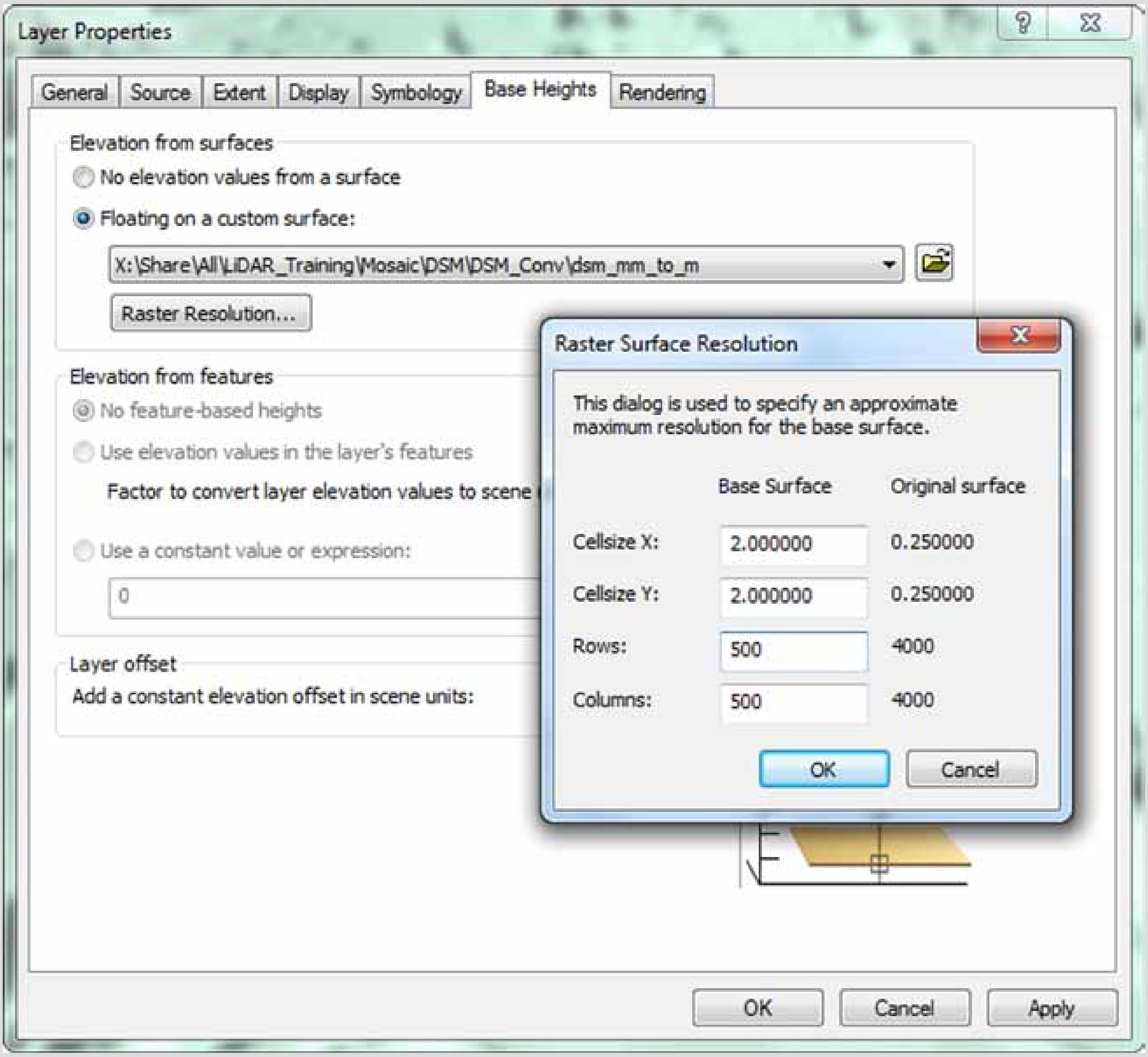
1. Open ArcScene.
2. Click on the 'Add data' tool and navigate to the folder Mosaic and go into the 'DSM folder', then into the 'DSM_Conv' folder and select the 'DSM_mm_to_m' file.
3. Right click on layer and select Properties.
4. Under Symbology tab, click on 'Classified' on left-hand side.
5. Select 1 class and select colour (a light colour is usually better).
6. If you have sea and land, you could select 2 classes, then click on classify, and set the Break value for the first class to 1 metre. Then click OK and change the colours of each class (i.e. to blue and green).



The Raster image now requires a height value:

7. Under Base Heights tab, select ‘Floating on a custom surface’ then click on Raster Resolution.

8. You now need to select a cell size – 2 metre for X and Y will create a manageable dataset (lower, and the data frame will slow down considerably, although when it comes to exporting images, you may want to drop this to 1 or 0.5 metre resolution).



9. Now select the Rendering tab and click on the tick box for 'Shade areal features relative to the scene's light position'.

10. Click OK and the 3D surface will appear in the window.

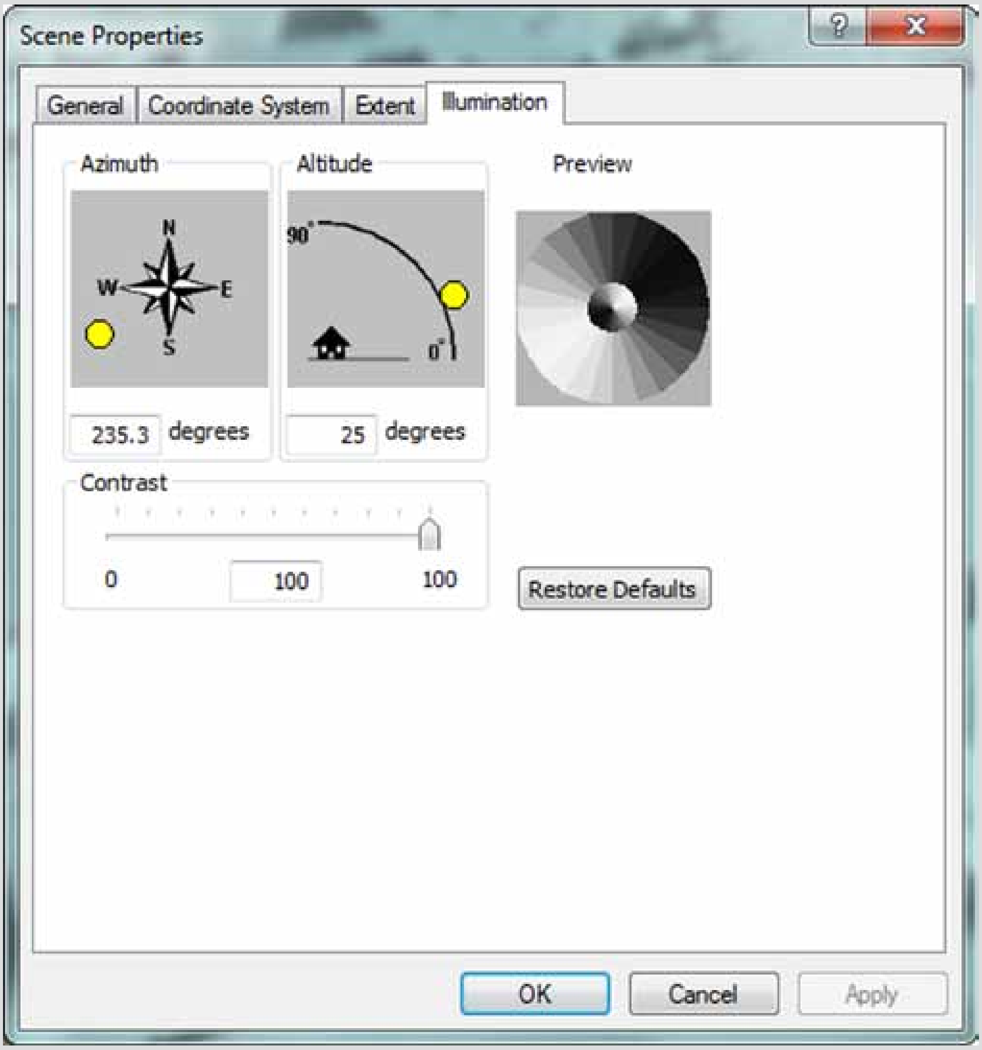
11. You now have a 3D DSM model, so repeat for DTM.

Once the 3D models have been projected, we can heighten the contrast and change the illumination so that features stand out:

12. Right click on Scene layers and select 'Scene Properties'.

13. Set Contrast to 100, and Azimuth (choose any) and Altitude (usually 25 degrees).

14. Click OK.


Scene Properties
General
Coordinate System
Extent
Illumination
Azimuth
Altitude
Preview
N
W
E
S
90°
0°
235.3
degrees
25
degrees
Contrast
0
100
100
Restore Defaults
OK
Cancel
Apply

3.3.2 Projecting shapefiles and rasters in 3D

You can now add shapefiles or raster and drape them over the 3D surface (Figure 6).

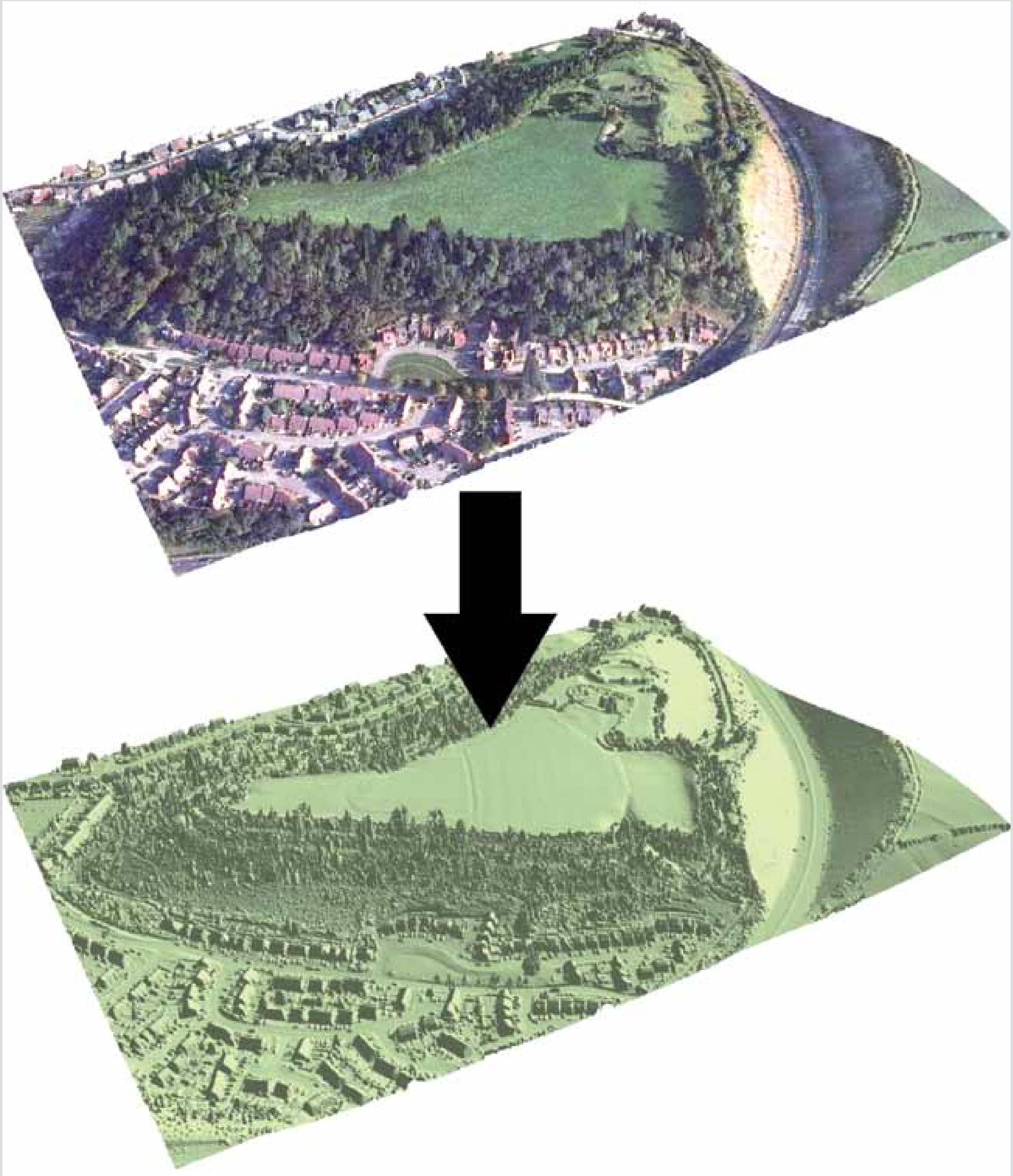
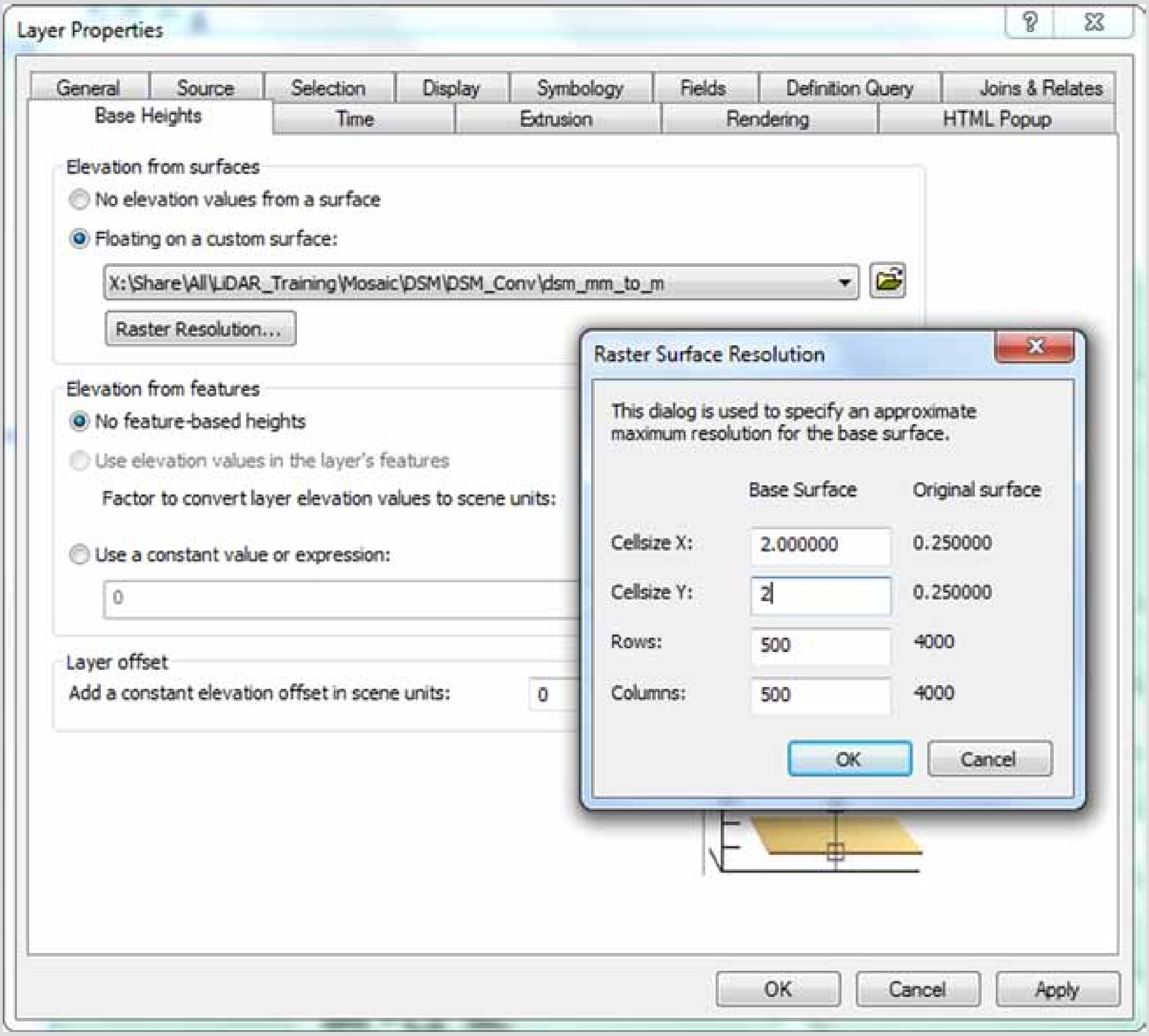


Figure 6: Georectified vertical images can be 'draped' over a LiDAR surface to produce a digital elevation model (© Crown: All rights reserved. Environment Agency, 100026380, 2011. Funded by the Royal Commission on the Ancient and Historic Monuments of Wales, Cadw, Welsh Government, and National Museum Wales. LiDAR view generated by RCAHMW).

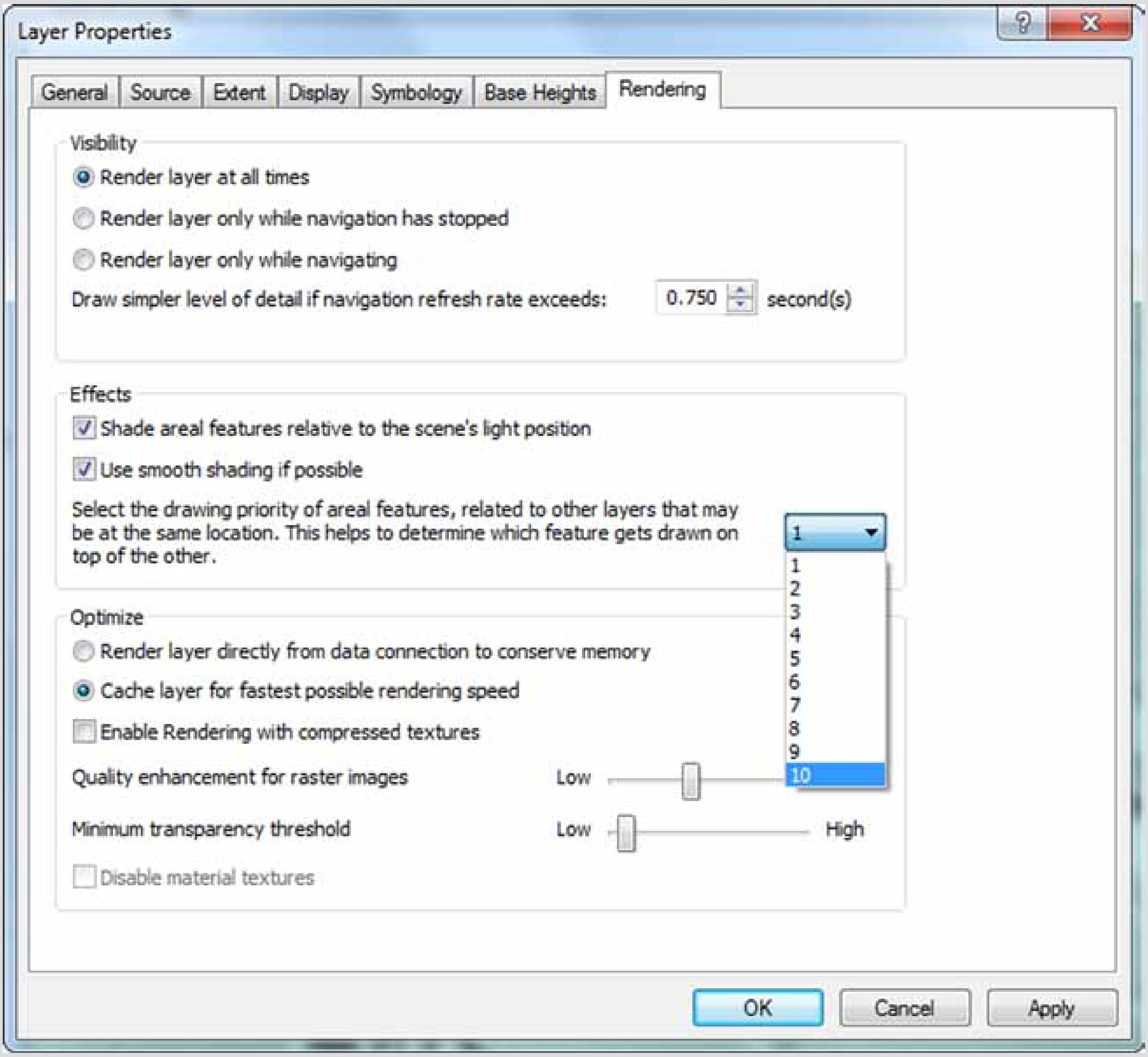
To add shapefiles and rasters:

1. Click on the ‘Add data’ tool and add your shapefile or raster.
2. Right click on layer and select Properties.
3. Under Base Heights tab, select ‘Floating on a custom surface’ then click on Raster Resolution.
4. You now need to select a cell size – 2 metre for X and Y will create a manageable dataset (lower, and the data frame will slow down considerably, although when it comes to exporting images, you may want to drop this to 1 or 0.5 metre resolution).
5. Click OK.



Finally, you need to change drawing priorities so that the surface is the lowest priority and all the layers sit on top:

1. Right click on 'DSM_mm_to_m'.
2. Select the rendering tab and in the drop-down menu for drawing priority, set to 10.



4.0 Further Reading

For those who have access to or are planning to commission a LiDAR survey, it is recommended that these guidelines are read in conjunction with:

Crutchley, S. 2010. *The Light Fantastic: Using Airborne LiDAR in Archaeological Survey*. Swindon: English Heritage.

Key texts for more information on LiDAR and its application for archaeology:

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