Long Paper

Flying High! Combining Old with New Methods for Enhanced Airborne Prospection and Characterisation

Integrating UAV-Based Remote Sensing with Traditional Survey Methodologies

Joel GOODCHILD, Archaeological Research Services, United Kingdom
Roger DOONAN, Archaeological Research Services, United Kingdom
Robin HOLGATE, Archaeological Research Services, United Kingdom
Clive WADDINGTON, Archaeological Research Services, United Kingdom

Abstract: Reference to aerial photographs and lidar imagery by trained specialists provides a well-established means of rapidly identifying and mapping archaeological monuments over large areas. In the United Kingdom, archaeological sites and features have been comprehensively mapped across fifty percent of the country as part of Historic England's Aerial Investigation and Mapping Programme. In recent years emerging Unmanned Aerial Vehicle (UAV) technology has been integrated with a range of survey and imaging sensors, creating the opportunity to deploy UAV-based lidar, multispectral and thermal imaging in addition to traditional aerial prospection methodologies. Broadening the range of techniques utilised within aerial survey may help to overcome some of the challenges commonly associated with individual techniques, thereby increasing the chance of successfully identifying and characterising heritage assets across a range of landscapes during large-scale aerial mapping projects. This paper highlights some of the limitations faced by current aerial survey methodologies with reference to two case studies: an aerial investigation and mapping project focused on the Cheviot Hills in Northumberland, Great Britain (Goodchild, 2022) and an archaeological excavation undertaken as part of a large infrastructure project in the UK. It suggests ways in which these may be addressed and overcome through the incorporation of UAV-based remote sensing.

Keywords: *Aerial—Survey—Multispectral—Lidar—UAV*

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Introduction

Aerial survey provides a rapid, cost-effective means of identifying and mapping heritage assets across large areas. For this reason it is the preferred method of survey for Historic England (HE), the public body responsible for England's historic environment, when commisioning mapping projects across landscapes where known and unknowwn heritage sites are deemed to be under threat from development. Traditional methods of aerial survey have made a huge contribution to increasing our knowledge of archaeological sites across England and the United Kingdom. Despite this, traditonal approaches to aerial survey have been hampered by limitations that result in sites being missed because they are not visible. By broadening the range of remote sensing techniques incorporated into aerial survey methodologies, visibility of heritage assets can be significantly increased by reducing the reliance on historic aerial photographs for cropmark detection and utilising high resolution drone-based lidar for the detection of subtle earthwork features.

In recent years emerging un-manned aerial vehicle (UAV) technology has been integrated with a range of survey and imaging sensors, creating the opportunity to deploy UAV-based lidar, multispectral and thermal imaging in addition to traditional aerial survey methodologies. These techniques provide the opportunity to map landscapes more comprehensively, allowing for the character and extent of archaeological sites to be better determined. This approach was pioneered by Dominic Powlesland (2006) at West Heslerton, demonstrating the value of combining airbourne remote sensing and geophysics datasets. Only recently have advances in UAV technology allowed such techniques to be utilised as a cost-effective means for archaeological prospection/evaluation, resulting in their potential contribution being explored more widely (James *et al.,* 2020). This paper will use two case studies to highlight the limitations of traditional aerial survey methodologies and address how these can be overcome with the incorporation of UAV-based remote sensing methodologies.

Traditional aerial survey approaches

The Northern Cheviot Hills Aerial Investigation and Mapping Project was completed by Archaeological Research Services (ARS Ltd) in October 2021 and funded by Historic England (HE) through the National Heritage Protection Commissions Programme (NHPCP). The aim of the project was to increase understanding and protection of Northumberland's historic environment by providing a comprehensive dataset of accurately mapped archaeological features from aerial sources to the Northumberland Historic Environment Record (HER) to inform future landscape management in a National Park. This was achieved by mapping and recording all archaeological features (earthworks, cropmarks, soilmarks, parchmarks and structures) visible on aerial photographs and lidar imagery where available. The study involved the systematic study of all aerial imagery covering an extensive project area of 104km^2 in the Northumberland National Park England, centred on the northern Cheviot Hills.

The project provided the opportunity to comprehensively map a landscape that has beguiled generations of archaeologists since the surveys of Henry MacLaughlan in the mid-nineteenth century. The Cheviot Hills are renowned for extensive survival of archaeological earthworks in its uplands and river valleys. Modern cultivation has barely intruded on the landscape, resulting in the preservation of earthworks representing Bronze Age, Iron Age, Roman and medieval activity across the uplands on a scale virtually unmatched across much of Britain and Europe (Waddington and Passmore, 2016). The favourable combination of geological and geographical factors has resulted in archaeology being visible across lowland and upland landscapes, offering a rare opportunity to interrogate the interaction of these contrasting areas since settlement of the Cheviots first began (Passmore and Waddington, 2012).

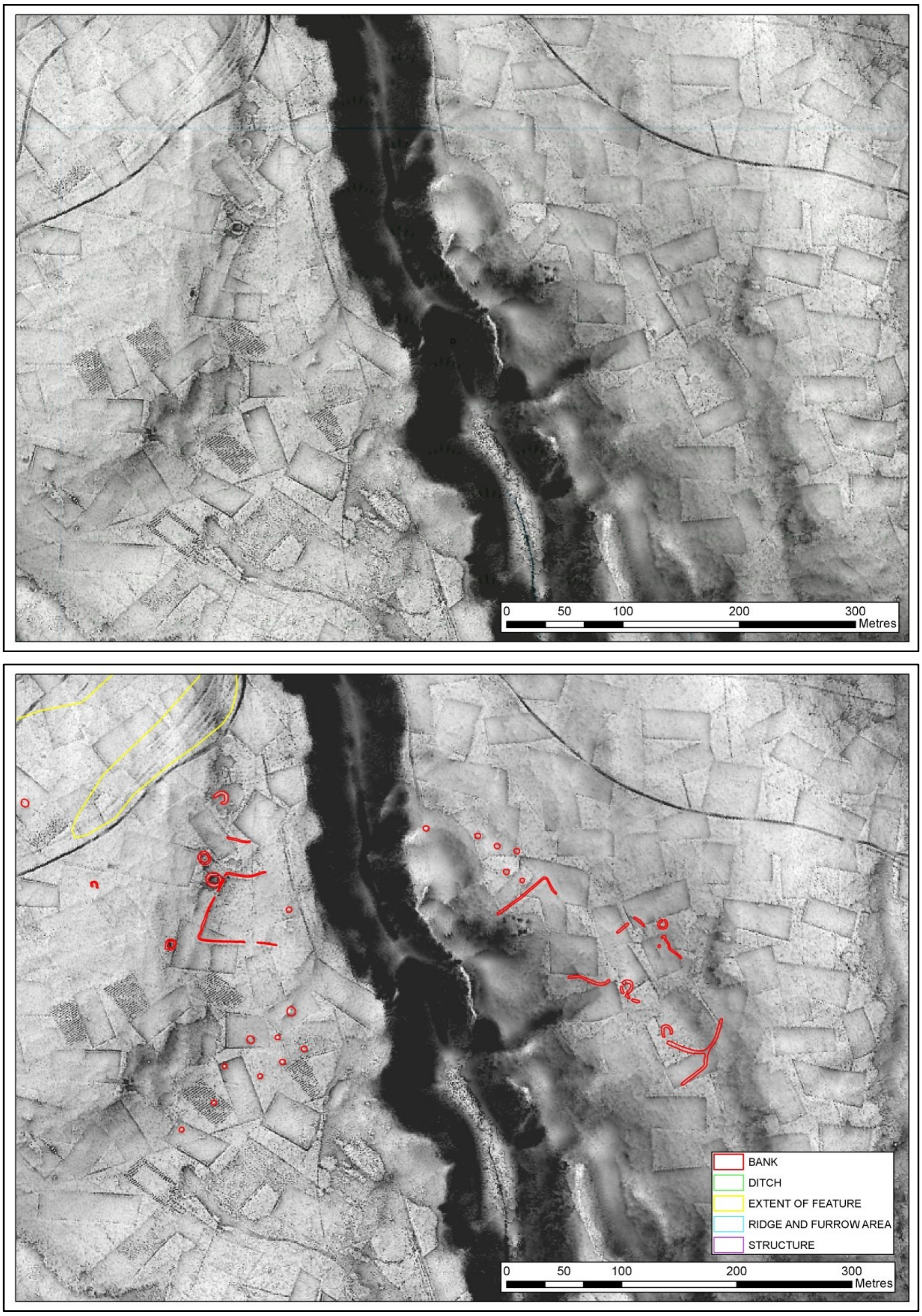

Fig. 1. Comparison of features visible at Houseledge in lidar with features mapped for oblique aerial photography and lidar (© Environment Agency copyright 2022. All rights reserved).

Sustained archaeological interest has resulted in the identification of hundreds of archaeological sites visible as earthworks across the Cheviot uplands, but little sense of how these sites relate to each other could be gleaned from the mass of points that had accumulated in the HER. Aerial investigation and mapping to HE standards (Winton, 2019) provided the opportunity to engage with the landscape in its entirety, establishing the relationship between archaeological sites through comprehensive mapping of visible archaeological features with reference to all available historic aerial photographs and 1m resolution lidar imagery.

The project resulted in a 44% increase in the number of known monuments in the Historic England Research Records database and a 5.6% increase in the local Historic Environment Record, the apparent mismatch between these figures reflecting the long tradition of local study within the region so that newly recognised features could often be associated with known sites. Building on the work of pioneering archaeologists such as George Jobey and Colin Burgess, the use of 1m resolution lidar greatly increased the number of Bronze Age settlements recognised in the area, as well as further defining features associated with such sites where they had already been identified. Bronze Age sites in the Cheviot Hills are often visible as subtle earthworks defining groups of enclosed and unenclosed hut circles. Such sites are the earliest manifestation of evidence for settlement in a landscape replete with archaeology.

Early Bronze Age settlements of unenclosed hut circles excavated by Colin Burgess (1984) at Houseledge East and West represent the earliest excavated evidence of settlement in the project area. At Houseledge West, five hut circles are visible as earthworks alongside an associated field system and cairnfield. The Houseledge settlements raise the interesting question of the visibility of archaeological remains using different sources. 1m resolution lidar proved to be of insufficient resolution for the recognition of subtle earthwork features such as the field boundaries, with only some huts visible in lidar (Figure 1). Mapping of these features was largely reliant on aerial photographs captured by Tim Gates in March 1985, in which earthwork banks are made visible by heightened vegetation protruding through a fortuitous quantity of snow. The lack of visibility in lidar is likely the result of 1m resolution lidar simply not being sufficient to capture slight earthworks that are less, or little more than 1m wide or high (Goodchild, 2022).

The geology of the northern Cheviots makes it particularly conducive to the formation of cropmarks, being characterised by freely draining sandy and loamy soils concentrated on the upland fringes of the Cheviots and in the valley floors (Cranfield Soil and Agrifood Institute, 2018). Such conditions are ideal for cropmark formation and a significant number of sites within the study area were identified by cropmarks. The site of Yeavering was discovered through aerial reconnaissance by J.K.S. St Joseph in the 1940s and was soon recognised as belonging to Ad Gefrin (the Britonic name used by the Anglians meaning ‘hill of the goats’), the Anglo-Saxon royal centre described by Bede. Situated atop a prominent glacio-fluvial river terrace overlooking the River Glen, the site was excavated by Hope-Taylor between 1953 and 1962, revealing a multi-phase site of great complexity (Hope-Taylor, 1977). The site exhibits continuity from the Neolithic to the Early Medieval period as a ritual and royal center. It has been 80 years since St Joseph’s photographs were taken, yet they remain the most comprehensive in detailing features at the site.

The intermittent visibility of archaeological features at Yeavering highlights a second limitation faced by traditional methods of aerial survey: identification of archaeological sites is dependent on them happening to be photographed when the overlying crop is under sufficient stress to result in cropmarks. Aerial photograph interpreters study all available archive photographs of a particular area in order to maximise their chances of identifying sites as cropmarks, but these efforts will always be limited by a range of factors, each of which can preclude the formation of cropmarks (Figure 2).

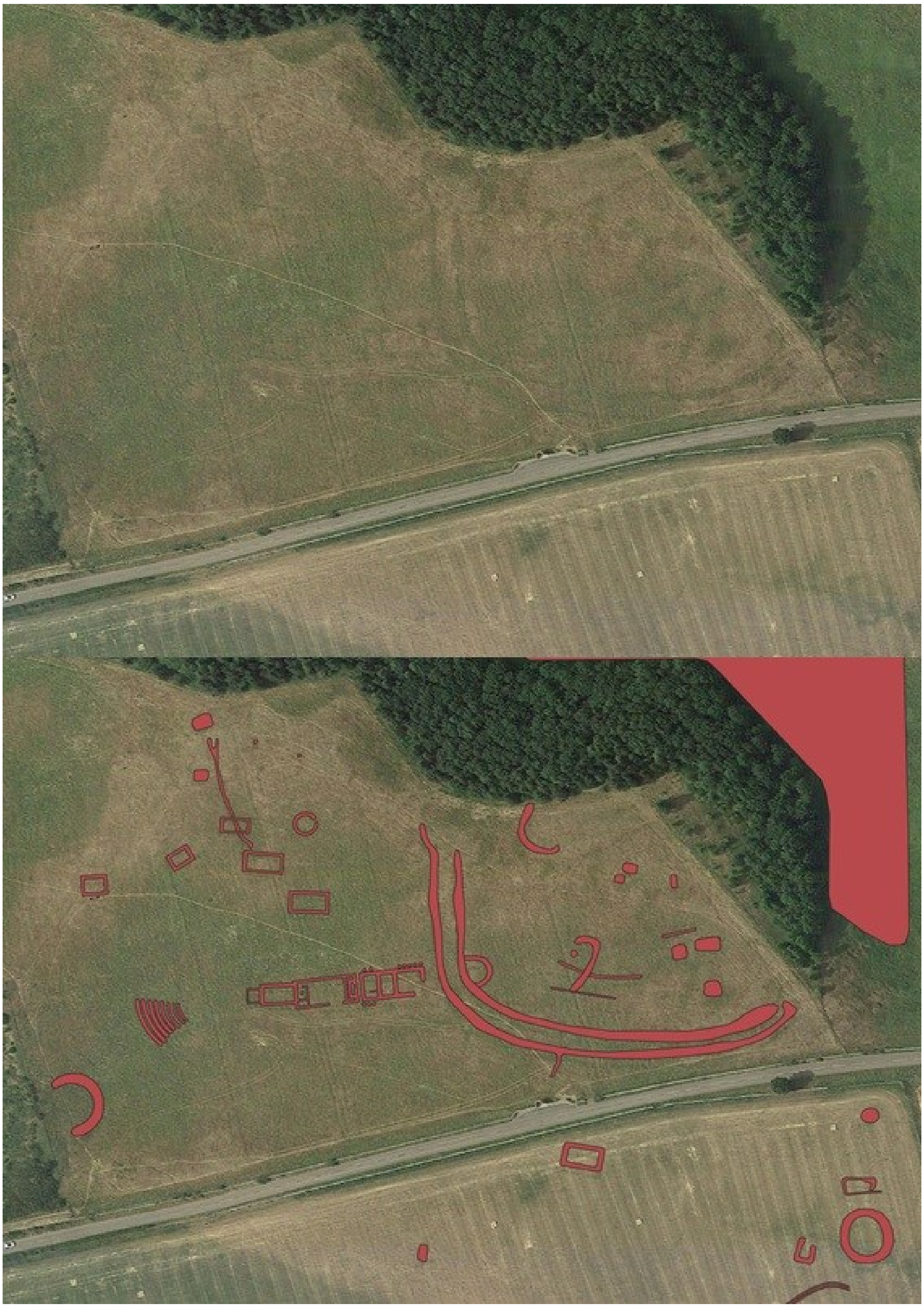

Fig 2. Comparison of features visible at Yeavering in Google Earth imagery with features mapped using aerial photographs as part of the Northern Cheviots AI&M project. (© ARS Ltd, Google Earth).

This limitation was highlighted at Lower Radbourne, Warwickshire, the site of a medieval settlement identified from aerial photographs. An aerial photograph taken by J. Pickering in 1962 captures extensive cropmarks that show the site in great detail. Of these features, only the most pronounced are regularly visible as cropmarks and these would not be sufficient to allow the site to be properly characterised in isolation. Lower Radbourne highlights the issue that many archaeological sites are likely to be missed by traditional aerial survey methodologies.

Enhanced methodologies: UAV-based remote sensing

Multispectral imaging is a well-established technique for mapping archaeological features, capturing spectral regions such as the red-edge (~700 nm) and near-infrared (NIR ~700 to 1100 nm) that lay beyond what is visible to the naked eye. By targeting those wavelengths most likely to capture variation in reflectance related to crop stress, interrogation of multispectral images allows for archaeological features to be identified even when crop stress is insufficient to result in visible crop marks. Variation in the surface temperature of soil and crops can also be affected by the presence of archaeological features. The temperature variations that result from differential retention of thermal infrared radiation (TIR) by archaeological and geological features can be detected using thermal imaging cameras.

During the summer of 2021 ARS Ltd carried out aerial surveys of Yeavering and Lower Radbourne using a UAV mounted with a multispectral and thermal imaging camera. As a result of the closure of the Cambridge University Collection of Aerial Photography (CUCAP), St Joseph's photographs of Yeavering could not be consulted as part of the survey. Despite this, the range of aerial photographs available to the project was sufficient to comprehensively map features at the site. Project mapping of these features allow for a useful comparison to be drawn between those visible through traditional aerial mapping methods and those through multispectral and thermal imaging. Figure 3 shows the results of thermal imaging survey at Yeavering compared to the red, green, blue (RGB) composite captured during the same flight. Comparison between these images shows that on a day when there are no discernable cropmarks in the RGB composite, thermal imaging clearly captures temperature variations that define the most significant archaeological features, with temperatures ranging between 28 and 31°C across the survey area.

Overlapping aerial multispectral/thermal photography was collected for the entirety of the survey area using a 6-band multispectral camera. The area surveyed was pre-programmed prior to flight and flown autonomously along parallel flight-lines separated by a predetermined percentage of overlap. At each capture position five spectral images were stored (blue, green, red, red-edge, near infrared). Thermal imagery was also captured during the flight. The following survey parameters were applied:

Table 1. Multispectral survey parameters employed in both case studies

Survey Parameter	Value
Side Overlap	70%
Forward Overlap	80%
Flight Altitude	60m
Speed	10m/s
Ground Sampling Distance (GSD)	2.4 cm/pixel
Spectral Bands captured	Blue, Green, Red, Red-edge, Near Infrared and Thermal

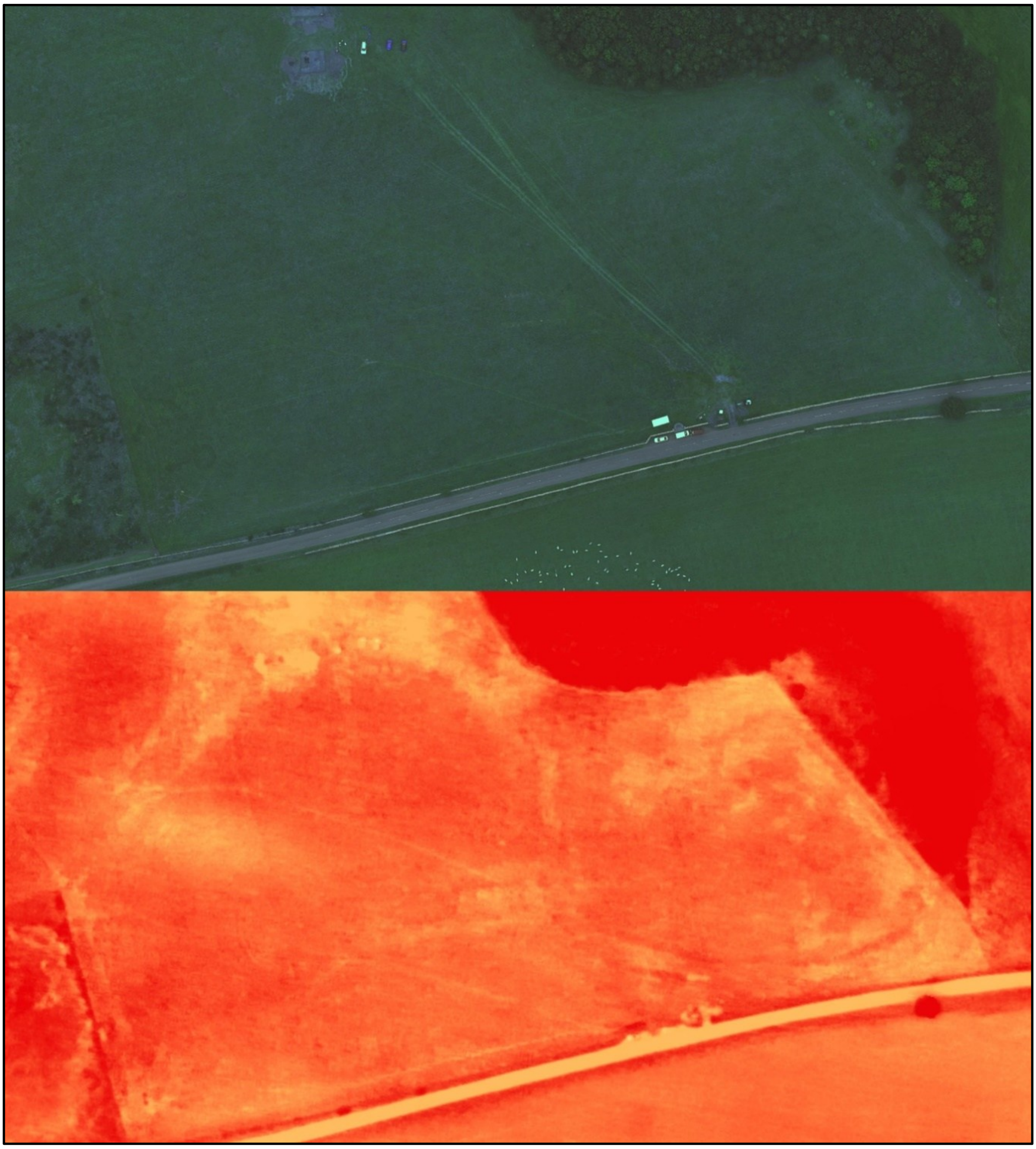

Fig 3. Comparison of features visible at Yeavering in RGB and thermal composite imagery. (© ARS Ltd).

Normalised Difference Vegetation Index (NDVI) visualisation of the multispectral survey data captured at Lower Radbourne revealed variation in plant reflectance defining archaeological features relating to the medieval settlement in great detail. Reference to this image allows for the site to be mapped identified, characterised and mapped in detail. This can be compared with the RGB in which slight cropmarks are barely discernable and would not be sufficient to identify and characterise the site. Not only does multispectral survey provide a means of identifying archaeological features when cropmarks are not yet visible in conventional photography, the types of feature identified are different to those identified through geophysical techniques such as magnetometry, so that when survey results are viewed alongside each other a much fuller picture of the archaeological site emerges.

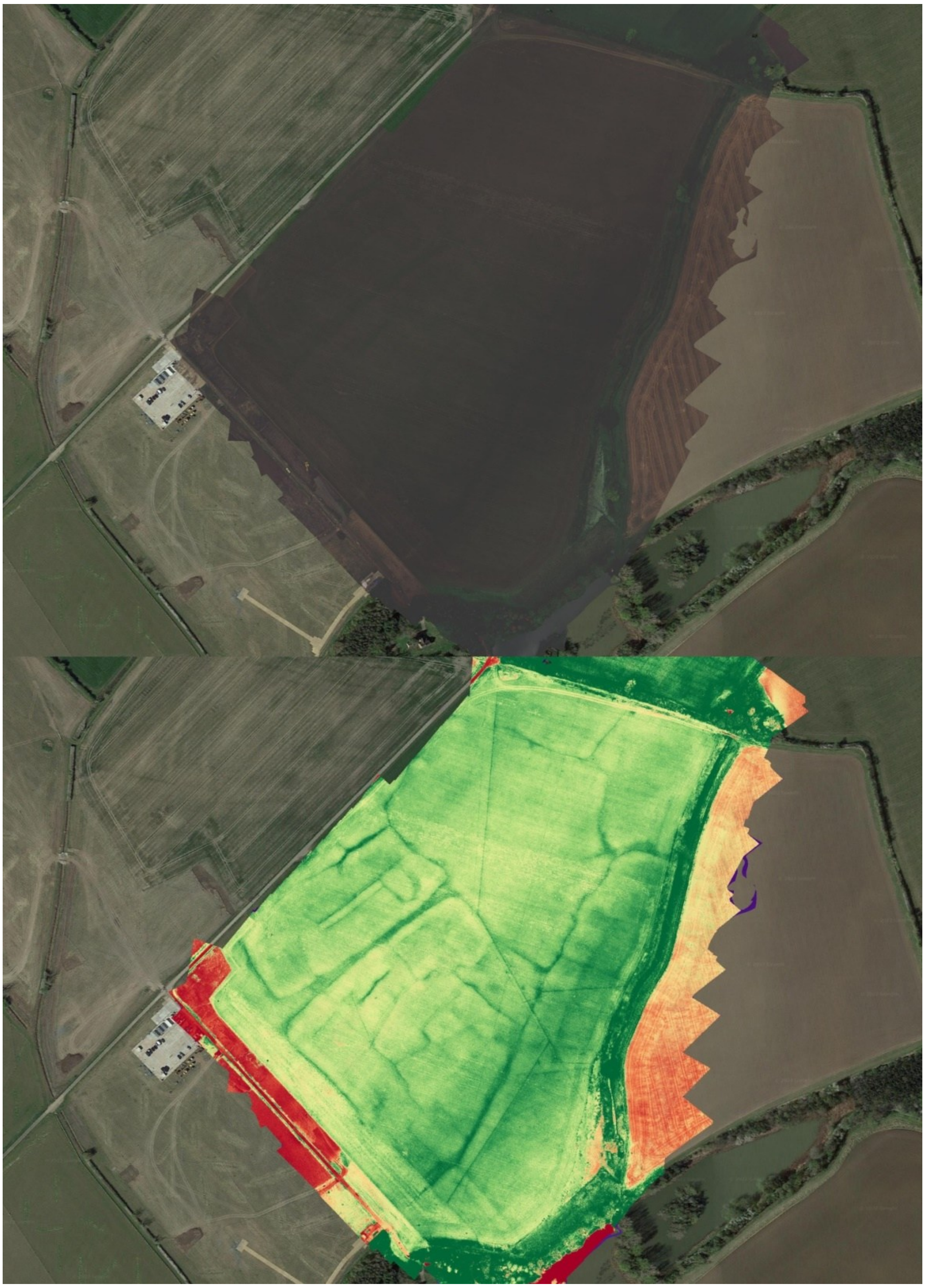

Fig. 4. Comparison of features visible at Lower Radbourne RGB and Multispectral composite imagery. (© ARS Ltd, Google Earth).

Conclusion

Augmenting traditional aerial survey methodologies with UAV-based remote sensing has the potential to revolutionise the way that sites are identified, characterised and mapped ahead of large-scale development and infrastructure projects. Traditional aerial survey techniques rely on optimal ground conditions and crop type in order to successfully identify heritage assets. Such assets are too often missed because conditions are sub-optimal and images have not been captured when features are visible. This can include both upstanding archaeology with subtle surface relief as well as buried remains. UAV-based remote sensing creates the opportunity to identify heritage assets in sub-optimal conditions both on the surface (high resolution drone-mounted Lidar) and buried below the surface (drone-mounted multi-spectral and thermal cameras), allowing for landscapes to be rapidly and accurately surveyed ahead of large-scale development/infrastructure projects. These data sets can be used for developing geoarchaeological landform maps as well as for mapping archaeological features, in addition for use in other disciplines utilised in the Environmental Impact Assessment process such as ecology, landscape, engineering design and restoration. This non-intrusive data can be used to better quantify the archaeology resource, assist with understanding its significance as well as being used, together with the geoarchaeological characterisation (see paper by Waddington this volume), to drive schemes of evaluation and ultimately mitigation. The results of geophysical techniques such as magnetometry are increasingly being negatively affected by the spreading of ferrous 'green waste' on fields masking archaeological features (Gerrard, 2016). Novel remote sensing techniques provide the opportunity to broaden our approach to landscape prospection, increasing the chances of identifying sites when ground conditions limit the efficacy of a single approach. Where the approaches outlined here are combined with other evaluation/prospection techniques that measure other independent signatures, such as geochemistry and geoarchaeology, a much more detailed, accurate and holistic picture of the archaeological potential of a landscape will become visible to us.

Author Contributions

Conceptualization: Waddington, Holgate and Goodchild
Data curation: Goodchild
Formal Analysis: Goodchild
Funding acquisition: Waddington and Holgate
Supervision: Waddington and Holgate
Writing – original draft: Goodchild
Writing – review & editing: Doonan, Waddington and Holgate

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