# Remote sensing in archaeology – from optical to lidar

**Time, space and the dynamics of change in archaeology**
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# Introduction

Remote sensing surveys provide a rapid means of data collection that can achieve complete coverage of large areas, with far lower costs than those associated with excavation or field survey. Traditional invasive methods generally damage or destroy the resources they were designed to investigate. Remote sensing methods, on the other hand, are non-destructive and leave the resource intact. Remote sensing in archaeology is an evolving enterprise, largely owing to rapid advances in technology, but also to the changing needs and goals of the discipline. Archaeological remote sensing allows large regions to be rapidly investigated for archaeological features, at relatively low cost; it can detect features unseen on the surface, map them accurately, and offer interpretations based on their form, distribution, and context (Kvamme, 2005).

Remotely sensed images have been used in archaeology for about a century. The first known aerial photographs of an archaeological site – Stonehenge – were taken from a war balloon in the early 1900s (Kvamme, 2005). Aerial photography, widely used in the first part of 20th century, has been almost surpassed by multispectral (especially high-resolution) satellite sensors and complemented with ground based instruments, such as ground based radar or lidar. Image interpretation and processing has now become a standard archaeological tool, and the use of aerial photographs, satellite imagery and other remote sensing techniques has become increasingly sophisticated particularly because digital spatial imagery has become ever more ubiquitous. Internauts all over the world are using tools like Google Earth or Microsoft Virtual Earth to observe and to interpret areas of their interest. Much of human history can be traced through the impacts of human actions upon the environment. The use of remote sensing offers archaeologists the opportunity to detect these impacts, which are often invisible to the naked eye. This information can be used to address issues in human settlement, environmental interaction, and climate change (Kvamme, 2005).

Aerial photography is the oldest and most widely used domain of archaeological remote sensing and receives the greatest focus, but other sensing devices have been placed in the air in recent decades, including passive multispectral and thermal sensors, and active radar and laser altimeter systems, making aerial remote sensing truly multidimensional (Kvamme, 2005). A number of satellite systems have played a significant role in archaeology. Landsat was the first satellite program for collecting repetitive, synoptic, multi-spectral imagery for monitoring and analysing Earth's resources and environment. Landsat and, later, SPOT were important in the early development of archaeological space-borne remote sensing, and continue to be used extensively. Early studies with satellite data focused on environmental zone or land-cover mapping, because spatial resolutions were too coarse for archaeological sites and features (Kvamme, 2005).

*Figure 1: SIR-A data indicate that the Sahara region was not always the dry desert it is today (NASA, 2001).*

In the early 1980s the Space Shuttle Imaging Radar (SIR-A) captured archaeologists' attention by revealing ancient canyons and paleochannels buried metres below the Sahara desert: the microwaves easily penetrated the subsurface of dry sands with a low dielectric constant (El-Baz, 1997). Many other radar systems (e.g. ERS and Radarsat) have been successfully used since then. The Shuttle Radar Topography Mission, flown on the space shuttle in 2000, created detailed digital elevation models covering 80% of the Earth's land surface by radar interferometry. The model with a resolution of 30 m provides an excellent tool for regional archaeological analyses.

High (spatial) resolution satellite imagery, with a resolution in the range of 1 m, is able to detect and map individual archaeological features (Fowler, 2002). In 1999, the Ikonos satellite was launched, followed by QuickBird in 2001; these commercial satellites offer multispectral data at 4 m and 2.4 m spatial resolutions, with panchromatic data at 1 m and 0.6 m, respectively. Recent advances in laser altimetry, i.e. measurement of height using a laser rangefinder, make the acquisition of high-resolution elevation data simple. Lidar (LIght Detection And Ranging) is the optical equivalent of radar, an active instrument capable of rapidly generating accurate and dense digital models of topography as well as the vertical structure of other surfaces (buildings, trees) from the air. Lidar is a technology providing remarkable surface detail, with absolute vertical accuracy to a few centimetres, even in vegetated areas, and horizontal sampling densities well below a meter. The huge potential of lidar has been already recognised, especially when combined with multispectral data.

## Search for anomalies

The primary aim of archaeological remote sensing is to find contrasts between archaeological features and the natural background. When archaeological deposits or features possess physical properties different from those of the surrounding matrix, a distinction may be noticed. A buried stone foundation might be more magnetic, better reflect radar energy, more slowly emit thermal energy, and stunt overlying plant life, compared with its surroundings. Contrasts are referred to as "anomalies" until they can be identified, a task that may require excavation. Frequently, anomalies can be perceived as a pattern sufficiently clear for direct interpretation, e.g. when the rectangle of a house foundation is unambiguously expressed (Kvamme, 2005).

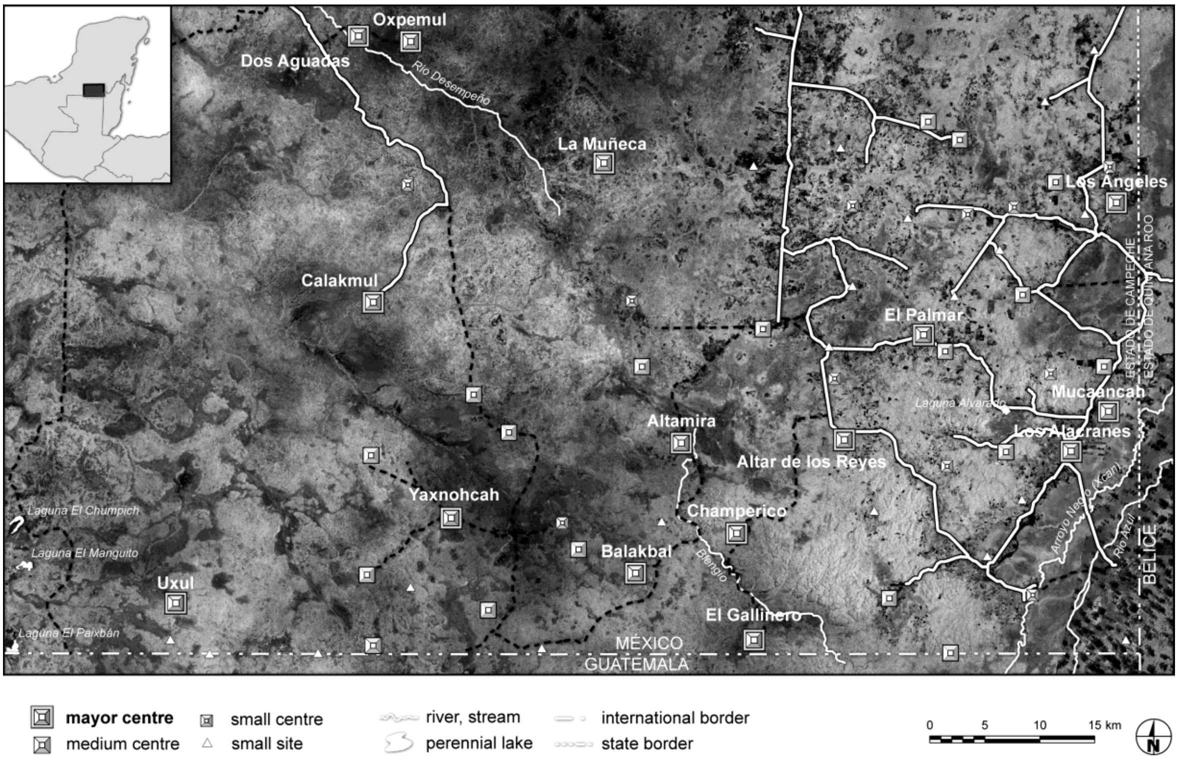


*Figure 2: Archaeological sites in the central Yucatan, Mexico, displayed over NDVI obtained from Landsat satellite image (Oštir, Kokalj, & Šprajc, 2006).*

There are several methods of identifying the locations of archaeological sites from remote sensing data. To be able to identify archaeological sites, subtle variations in spectral response had to be detected (Oštir & Nuninger, 2006). The need to use multi-temporal and multi-scalar imagery to confirm potential anthropogenic anomalies and exclude transient environmental phenomena and data errors has been demonstrated. Sever and Irwin (2003), for example, have tried to detect linear features that might be related to – Mayan – roadways or channel systems, to correlate settlement patterns with vegetation, hydrological, and geological features on the karst landscape, to isolate topographic features where sites are likely to be located, and to create detailed maps of vegetation and drainage pattern maps, in order to provide insight into the relationships among land cover, paleohydrology, water management, bajo systems, settlement pattern and subsistence strategies. Rothaus and De Morett (2001) focused on the search for anomalies; because of the multiple indicators (variables) involved, as well as the uncertainty of the results, they used an approach based on visual detection rather than automated classification. They presumed that the use of landscape by prehistoric people associated with archaeological sites was similar as the one involved in contemporary swidden agriculture.

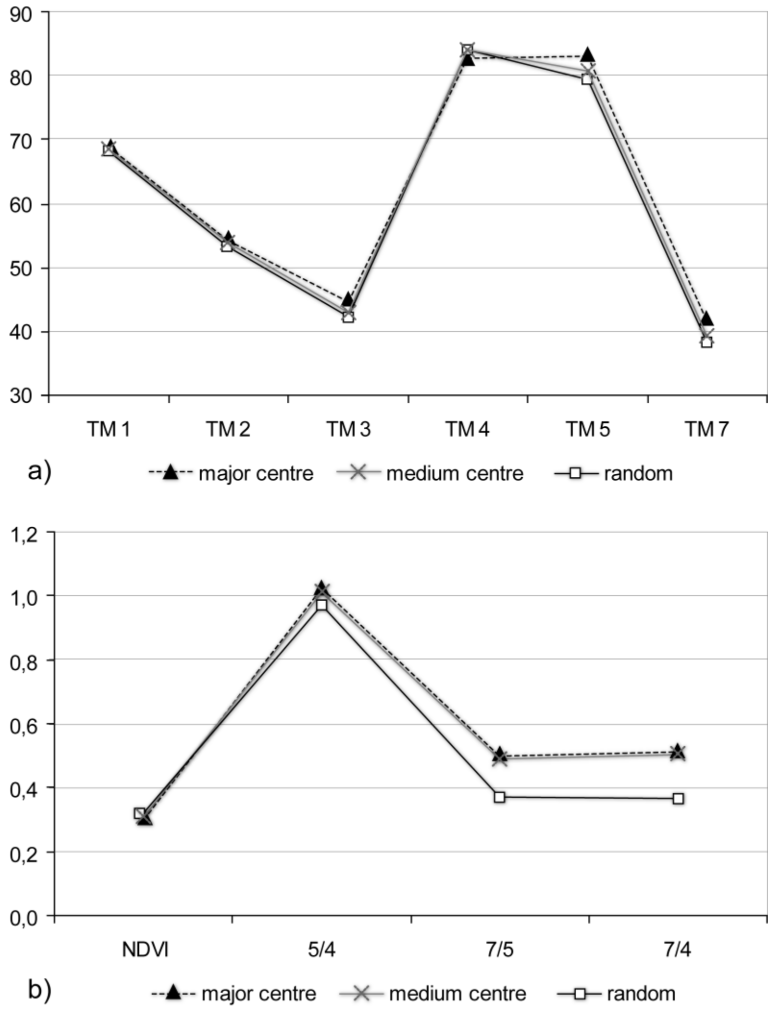


*Figure 3: Spectral signatures (a) and especially indices (b) show that larger sites differ from random points (Oštir, Kokalj, & Šprajc, 2006).*

While satellite remote sensing is one of the most discussed topics in archaeology, remarkably little has been published that details the steps researchers are using (Rothaus & De Morett, 2001). Computer manipulation and processing of data is now essential to nearly all remote sensing, nearly as important as collecting the actual data, because noise, defects, and distortions in raw imagery obscures important information (Mather, 2004). Various filtering and enhancement methods tease out hidden information, exposing subtle features (Richard & Jia, 2006). Frequently, general purpose image processing, photogrammetry, or GIS software (which often includes elements of the first two) contains all the necessary tools; special-purpose software is sometimes also required (Kvamme, 2005). The image analyses are mostly either visual or based on simple image enhancements (Sabins, 1997). Most of the basic tools for archaeological prospecting are based on inspection of aerial and satellite data and reconnaissance in the field. It is only recently that the potential of advanced processing methods has been realized. Different authors propose the use of high-resolution optical and radar images, and pattern recognition techniques, to support archaeological prospecting (Lira, López, & Rodriguez, 2005).

Despite the benefits, remote sensing is not a panacea for archaeology. It is constrained by conditions at the time and place of data acquisition potentially leading to poor or no archaeological feature contrasts; it is particularly difficult within urban or forested landscapes (Kvamme, 2005). The use of digital image analyses for archaeological prospecting does not preclude direct fieldwork – it is only a means to make a synoptic view of the area under investigation, reduce the costs of and enable more efficient field research. Archaeological sites are easily destroyed once they have been excavated, because they become exposed to the elements, visitors and, often, to looters. Modern archaeologists must consider all possible methods to preserve the sites they have unearthed and to examine others without touching them (El-Baz, 1997). It is probably only through remote sensing that archaeologists will be able to map, analyse, and interpret the ancient cultural landscapes over much of the globe (Kvamme, 2005).

## Lidar remote sensing

In recent years, lidar remote sensing is receiving a growing attention in specialized publications. The technology, developed in the 1970s for military purposes and topographic surveying, is being propagated intensively into other fields, e.g. energetics, natural hazard protection, agriculture, forestry, mining, urban planning, communications, and archaeology (Ackermann, 1999). The core of lidar technology is repeated measurement of distances to a certain object with laser ranging, which results in a spatial representation of the object. The distance is calculated from the time difference between the laser pulse emission and the received reflection. Lidar observations exceed most of optical remote sensing systems significantly, both in detail (up to several tens of reflections per square meter) and positional accuracy – horizontal and vertical absolute errors are in the range of 10 cm and less (Wehr & Lohr, 1999). In this sense the measurements are comparable to the high quality aerial photogrammetric recordings, but have a decisive advantage: the immediate rendering of the third dimension for every measured point. This is so because lidar is normally combined with devices for accurate positioning of the sensor and for measuring the orientation of the laser beam – GPS (Global Positioning System) and INS (Inertial Navigation System) – resulting in absolute location of reflection points. The need for orthorectification and stereomodelling, required in the case of aerial photography, is therefore eliminated (Baltsavias, 1999). An excellent review of lidar remote sensing can be found in a special issue of ISPRS Journal of Photogrammetry & Remote Sensing (1999, vol. 54 no. 2-3).

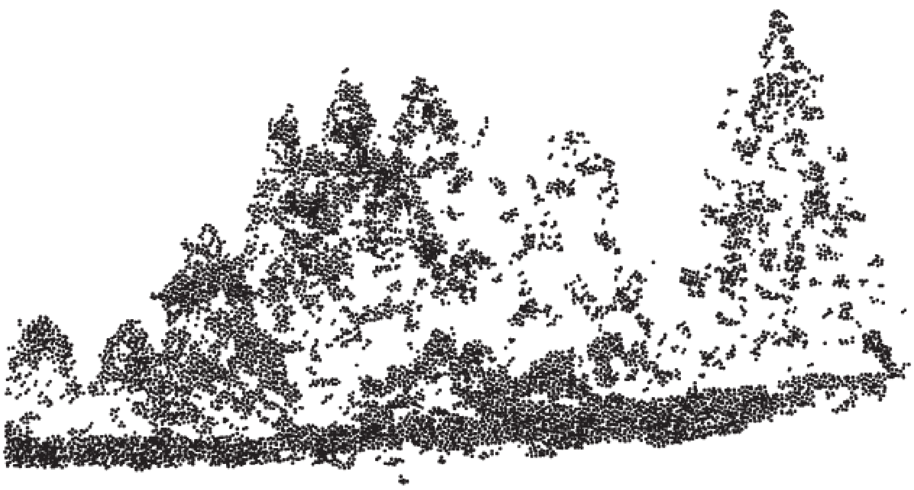

*Figure 4: Lidar data point cloud.*

The term lidar is an acronym for Light Detection and Ranging or Laser Imaging Detection and Ranging, a technology that determines distances to objects or surfaces using laser pulses (functioning in a way very similar to radar). Lidar systems produce two datasets – a precise position and orientation of the platform, obtained from GPS (Global Positioning System) and INS (Inertial Navigation System), and range or distance to the observed objects. By joining both datasets one can compute the positions of reflectance points. An attribute – usually the reflectance order (first, second … last) or intensity – is assigned to each point. The final result of observation is a point cloud, representing reflections on the ground, vegetation, and artificial objects. In comparison with most optical remote sensing systems, lidar measurements are much more detailed and positionally accurate, comparable to high quality aerial (photogrammetric) imaging, but have a decisive advantage of showing three-dimensional information without additional processing. The coordinates of lidar responses are absolute, eliminating the need for orthorectification or stereo modelling.

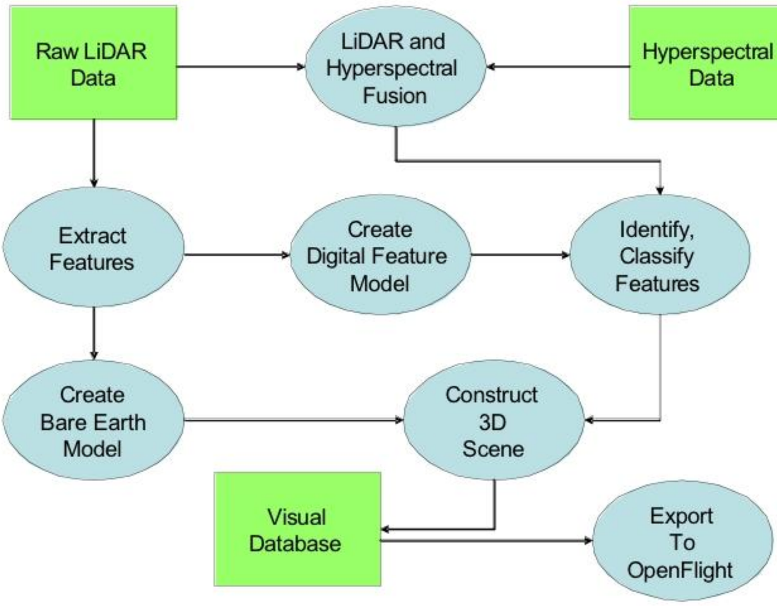


*Figure 5: Lidar data processing chain (Rex, Fairweather, & Halligan, 2005).*

Lidar remote sensing data contains a wealth of information that has to be extracted from point cloud data before interpretation. Digital elevation model, a – generally raster – layer representing the shape of the Earth's surface, is the most important product of lidar data processing. Additionally, lidar allows the acquisition of vegetation characteristics, e.g. vertical profile, height, etc. Both the elevation and the vegetation cover models can be used in the analyses of past landscapes, since the relief shape and terrain characteristics, represented partially by vegetation properties, have influenced the settlement patterns and land use. With adequate data processing, products (images) revealing anthropogenic features, both modern (e.g. buildings, power lines, etc.) and those belonging to recent and ancient past (e.g. agricultural modifications of the terrain, a variety of structural remains from different archaeological periods, etc.), can be obtained.

While certain information about landscape changes can be obtained with optical remote sensing, e.g. with aerial photo interpretation, the use of optical images is, particularly in forested countries, very limited because many elements of past cultural landscapes are overgrown with vegetation. Lidar, with its ability to penetrate vegetation, presents the only available possibility to directly observe modifications of natural environment in the past and thus the detection of archaeological sites.

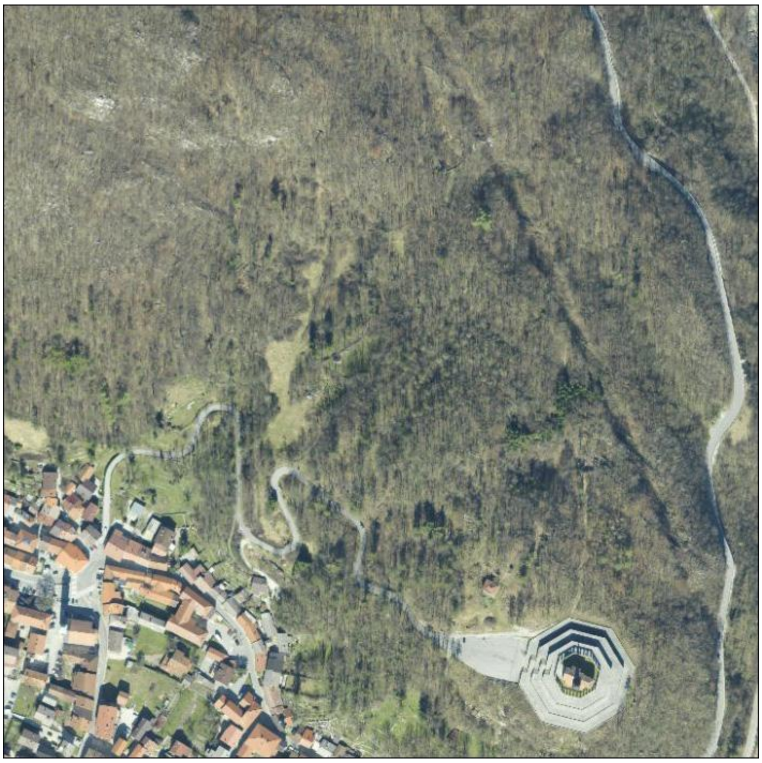

*Figure 6: Due to vegetation the remains of past cultural landscape are hardly visible on aerial photography. The image of Kobarid (Caporetto, Karfreit, WWI memorial is located in the lower right part) in north-western Slovenia was taken in March that is in low vegetation period.*

*Figure 7: Vegetation tops are detected by the first lidar return pulses.*

*Figure 8: Filtered elevations reveal some of the features connected with past human activity. Terraces, stone walls, entrenchments, plateaus, trenches ... can be observed and mapped. To reveal as many details as possible vegetation filtering was not extensive and some points belonging to vegetation remained in the relief.*

A crucial advantage of lidar in the study of past landscapes is its ability to penetrate forest canopies. This enables detailed mapping and surveying of overgrown archaeological structures (houses, ramparts, trenches, ditches etc.) (Bewley, Crutchley, & Shell, 2005), fossil fields and terraces (Sittler, 2004), ancient land division (e.g. Roman centuriatio), abandoned quarries and mining areas, burial mounds, ancient roads (Roman, medieval), and other elements of cultural landscape in specific environments, where other surveying techniques do not give satisfactory results (Challis, 2005). Despite its obvious advantages, lidar has only recently been introduced in the research of past cultural landscapes (Devereux, Amable, Crow, & Cliff, 2005). Additionally, only some of its potential has been employed; the researchers usually use processed data provided by lidar operators, overlooking a substantial amount of information contained in lidar point clouds. The knowledge and development of processing algorithms and their adaptation to particular needs offers space for innovations and better data analyses.

Lidar remote sensing is mostly carried out from aircrafts and helicopters, as well as satellites, while terrestrial lidar is also used for special purposes. Lidar instruments can be classified according to their key properties, such as the laser beam wavelength, pulse frequency, beam divergence and emitting power, which define their applicability (Wehr & Lohr, 1999).

A noteworthy characteristic is the extraordinarily large amount of data produced by lidar. Until recently, this was a major drawback hindering diffusion of its use beyond scientific community, since »manual« data analyses and visual photointerpretation were viable only for reduced spatial segments. The increasing power of computers and, particularly, the development of more efficient and robust algorithms for automatic data interpretation (Sithole, 2005), however, contributed to a wider applicability of lidar technology. The point clouds produced by the instrument contain the altitude data for the earth surface, including vegetation, buildings and other natural and anthropogenic features. In the case of relief model elaboration, the reflections from these objects have to be eliminated from the source data, applying filtering and segmentation (Hyyppä, et al., 2004). The most important parameters determining filtering methods are relief roughness, vegetation coverage, and urbanization level (Kraus & Pfeifer, 1998). A recent comparison of the effectiveness of different filtering methods determined that most of the algorithms are suitable only to particular landscape types and that only a combination of approaches enhances the results (Sithole & Vosselman, 2004). Better filtering methods have to be developed, especially in the forested areas, like the REIN (Repetitive Interpolation) algorithm that is more accurate and reliable than others known thus far (Kobler, Pfeifer, Ogrinc, Todorovski, Oštir, & Džeroski, 2007).

## Conclusions

The elements of cultural landscape can be recorded by field surveying, which continues to be inevitable for obtaining some detailed data. Remote sensing techniques, however, enable a much faster and more systematic information acquisition, and frequently also the recognition of features that, due to their configuration or environmental peculiarities, cannot be detected with traditional field reconnaissance techniques. Satellite and airborne remote sensing has therefore become a standard tool in archaeological research. The main focus of research is shifting to the application of high resolution and hyperspectral satellite images. In recent years, there has been a growing interest in lidar remote sensing, a technique that has not been widely used in archaeology, in spite of its great potentials.

To use as much of the potential contained in the remote sensing data as possible it is necessary to apply up-to-date processing methods. The outcomes obtained so far have clearly shown that only advanced, sophisticated processing methodology is able to provide reliable indicators of archaeological sites. Nevertheless, remote sensing is not able to eliminate fieldwork – it is only a means to make a synoptic view of the area, reduce the costs of and enable more efficient field research.

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