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Detection of exposed and subsurface archaeological remains using multi-sensor remote sensing

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Abstract

Multi-sensor airborne remote sensing has been applied to the Itanos area of eastern Crete to assess its potential for locating exposed and known buried archaeological remains, and to delineate subsurface remains beyond the current limits of ground geophysical data in order to permit future targeted geophysical surveys and archaeological excavations. A range of processing techniques (e.g., Reed–Xiaoli anomaly detection) have been applied to the CASI, ATM and lidar data in order to detect anomalies based on the premise that buried remains are likely to alter the physical and chemical characteristics of the soil compared with those of the surroundings due to variations in soil depth and drainage. Through a combination of CASI, ATM and lidar data, surface remains have been classified and mapped effectively using an object-oriented approach. The detection of subsurface remains is more problematic; however, the thermal data is most promising in this respect. The value of capturing multi- or hyperspectral data at a high spatial resolution has been demonstrated as well as the additional benefits of combining these with airborne lidar.

Keywords: Archaeology; Crete; Remote sensing; Hyperspectral; Thermal; Subsurface

1. Introduction

Remote sensing in the form of aerial photography (Bewley et al., 1999) as well as ground-based techniques such as ground penetrating radar, soil resistance and magnetic prospection, are well established and widely practised within archaeological research (Wynn, 1990; Theocaris et al., 1996; Gaffney and Gaffney, 2000; Sarris and Jones, 2000; Neubauer, 2001; Kvamme, 2003; Leckebusch, 2003; Sarris, 2005a). Such techniques have their merits but also have their disadvantages (e.g., geophysical surveys are time consuming, expensive and tend to be limited in their spatial extent; whilst features in the landscape that reflect beyond the visible spectrum are unable to be detected using conventional aerial photography). Airborne Light Detection and Ranging (lidar) as well as multi- and hyperspectral remote sensing are additional geo-archaeological tools, which have been used sparingly to date within this context (e.g., Montufo, 1997; Powlesland et al., 1997; Fowler, 2002; Banes, 2003; Shell and Roughley, 2004; Devereux et al., 2005; Challis, 2006). Most applications utilising remote sensing within archaeology take a single sensor approach, whereas the real benefits with respect to archaeological interpretation will be gleaned through a multi-sensor approach harnessing the different qualities of each sensor (e.g., Powlesland et al., 1997). Although presenting opportunities to the archaeological community, these sensors have their disadvantages that also need to be appreciated. This paper seeks to address these issues through a multi-sensor case study in eastern Crete. This data set constitutes a rare opportunity to employ high spectral and spatial resolution data in combination with lidar in an area of known dense subsurface and exposed archaeological remains.

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2. Remote sensing of archaeology

Depending on their configuration, multi- and hyperspectral data captured from both airborne and spaceborne platforms are attractive since they can detect electromagnetic radiation in the visible and beyond into the infrared and the thermal. With technological improvements, the higher spatial and spectral resolutions previously only attainable through airborne remote sensing are increasingly becoming available on spaceborne platforms [e.g., Hyperion (Krusel, 2003)]. Multi-spectral sensors such as Landsat and SPOT acquire data in broad (~100–200 nm) irregularly spaced spectral bands (van der Meer and de Jong, 2001). Consequently, narrow spectral features may not be readily discriminated due to averaging across the spectral sampling range or masked by stronger features (Kumar et al., 2001). The net effect is the reduction or loss in the information that can potentially be extracted. Hyperspectral sensors, comprising tens to hundreds of bands, are able to retrieve near-laboratory quality reflectance spectra such that the data associated with each pixel approximate the true spectral signature of a target material (Lucas et al., 2004). Given the cost implications of acquiring such imagery, the question arises; is it necessary to opt for both high spectral and spatial resolution imagery for archaeological applications? This paper addresses these issues and highlights the need to consider both the scale of the archaeological remains as well as their distinctiveness spectrally.

A number of different satellite sensors have been employed in a variety of archaeological applications spanning the identification of spectral signatures within archaeological sites (with direct consequences for predictive modelling) to the mapping of subsurface remains and the management and protection of archaeological sites (Ebert and Lyons, 1980; Custer et al., 1986; Madry and Crumley, 1990; Cooper et al., 1991; Liu et al., 2003a; Sarris et al., 1996). Typically these are based on low spectral and spatial resolution imagery [e.g., Landsat (Custer et al., 1986; Clark et al., 1998), SPOT (Clark et al., 1998; Sarris and Jones, 2000; Tripathi, 2005) and ASTER (Altaweel, 2005)]. Recently, high spatial resolution satellite imagery from the Ikonos and Quickbird sensors have been employed for the recognition of settlements and shallow depth monuments (Sarris, 2005b). The mapping of potential ancient settlements from former river courses through the identification of spectrally distinctive deposits (Gore, 2004) and the identification of surface archaeological remains directly (Parcak, 2004) are indicative of the range of remote sensing work previously conducted. Increasingly remote sensing, and time series remote sensing in particular, is being utilised for archaeological resource management/cultural resource management [e.g., to monitor encroachment onto sites due to population or agricultural pressures (Changlin et al., 2004; Raczkowski, 2004)]. Other applications include the use of multiple polarisation data from the Shuttle Imaging Radar (SIR-A, SIR-C) to provide evidence of palaeochannels in arid environments to locate areas that could have sustained settlements (McCauley et al., 1982; El-Baz, 1998), Radarsat Synthetic Aperture Radar (SAR) imagery for studying mound sites and canal systems (Richason, 1998), and the use of declassified intelligence satellite imagery for the construction of an archaeological GIS (Mathys, 1997). The latter, with emphasis on CORONA images, are increasingly used in archaeological applications (Philip et al., 2002; Ur, 2003; Fowler and Fowler, 2005; Goossens et al., 2006). Images derived from remote sensing then become important data layers within a Geographical Information System permitting monitoring and conservation plans to be implemented (Shupeng, 2004).

In addition to mapping surface remains, buried archaeology may cause anomalies in the characteristics of the overlying soil, which can be detected by remote sensing in the visible, near infrared and the thermal. The presence of buried remains is likely to alter the physical and chemical characteristics of the soil compared with those of the surroundings due to changes in soil depth and variations in drainage. However, extraction of soil-based information from remotely sensed sources is complicated by the presence of vegetation, which (a) obscures the pure soil signature and (b) attenuates electromagnetic radiation at most wavelengths (Tucker and Miller, 1977). Even in semi-arid regions dead vegetation masks soil reflectance with soil discrimination being lost at between 50% and 60% vegetation cover (Murphy and Wadge, 1994). Studies have demonstrated that hyperspectral remote sensing can retrieve information such as soil moisture content (Liu et al., 2003b), temperature and texture/surface roughness and given the distinct spectral signatures of minerals, have played a key role in identifying and mapping soils (Leone and Escadafal, 2001; Ben-Dor et al., 2002; Chabrillat et al., 2002; Metternicht and Zinck, 2003).

Although the case for the application of thermal imagery to detect buried features is well established, relatively limited use is made of thermal remote sensing within an archaeological context (e.g., Bellerby et al., 1990; Ben-Dor et al., 2001) but it has attracted more attention in the analogous application of sensing buried military ordnance, particularly mines (Maathuis and van Genderen, 2004). The principal premise for both is that heat transfer through the soil will be affected by the presence of buried objects (Maathuis and van Genderen, 2004). Shallow buried remains may be ideal targets for thermal sensors provided that they exist within the penetration depth of long-wave solar radiation (Nash, 1988) and if other factors such as the thermal characteristics of buried objects and the surrounding medium are favourable (Ben-Dor et al., 2001). In semi-arid regions, such as the study area, remains at deeper levels (i.e., several metres in depth), will be beyond the range of long-wave solar radiation and will only be detectable with sensors operating at microwave wavelengths (i.e., radar).

In the case of detecting buried ordnance, the nature of the target object is likely to have distinct thermal properties from the surrounding media; however, this may not necessarily be the case for archaeological remains. Environmental factors such as the compaction of soil (Winter et al., 1997), moisture content (Simard, 1996) and vegetation (Bishop et al., 1999) will impact on the effectiveness of the technique to detect subsurface remains. The presence of vegetation in the context of thermal sensing is complicating given the impact of evapotranspiration, which results in a uniform canopy temperature (Donoghue, 2001). The detection of buried remains using thermal imagery is likely to be enhanced through the acquisition of a time series of pre-dawn and mid-day image pairs in order to construct a Thermal Inertia Map as a measure of diurnal heat capacity. Since certain materials possess a strong inertial resistance to temperature fluctuations they show less temperature variation per heating/cooling cycle than those with lower thermal inertia (Cassinis et al., 1984; Cracknell and Xue, 1996; Majumdar, 2003).

3. Study area and data

To demonstrate the utility of such sensors, an exemplar data set for the Itanos area of eastern Crete is presented. Itanos (Erimoupolis) is located 10 km north of Palaikastro, in Lasithi prefecture, close to the Vai Palm Forest (Fig. 1). It was named after Itanus, one of the Kourites. Its harbour was of major importance for trade between Crete and the eastern Mediterranean, and its economic growth resulted in it being the first Cretan town to have a currency. The wealth of the sanctuary dedicated to Diktain Zeus, which continued to operate from the Geometric to the Roman times, must have played an important role in this. A 146 BC inscription, which today is part of the walls of the Toplou monastery, informs us about the interference of Pharao Ptolemeus Filomitor who helped Itanos in the conflict with the nearby town of Praisos. After the destruction of Praisos from Ierapytna, the conflict continued between the town of Itanos and Ierapytna. In 121/120 BC, Itanos and Lato were involved in a conflict with Olounta and Ierapytna. Itanos is marked mainly from three periods: Geometric, Roman and Early Byzantine, while the exact periods of original occupation and abandonment are not well established. During the Roman conquest and the first Christian times, the town continued to flourish, until it was gradually destroyed, probably by the Arabs (Sanders, 1982; Spyridakis, 1986).

The archaeological site covers approximately 16,000 m^2, of which only 1% has been excavated. Most of the structural remains of the settlement are seen in the region between the Acropolis. A defence wall is partially obvious at the SW above the sloping terraces that separate Itanos from Vai. Archaeological remains at the site include two First Byzantine basilicas, a large Hellenistic cemetery, an observation tower, isolated tombs, etc. The harbour and the coastal installations seem to have been covered by alluvial deposits, a process which has been attenuated by the rise in sea level due to local tectonic activity. The latest excavations at the site were initiated in 1993 by a collaborative campaign between the French School of Archaeology at Athens and the Institute for Mediterranean Studies (Greco et al., 1996, 1997, 1999, 2001). Within the framework of the campaign, a systematic geophysical survey has been conducted in the region combining soil resistance mapping, 2D and 3D electrical tomography, magnetic mapping, electromagnetic mapping, seismic refraction and ground penetrating radar (Sarris et al., 1998; Vafidis et al., 1996, 2003a,b). Seismic data were able to map the depression of the ancient harbour, the eastern section of which reaches a depth of about 30 m. The basement consists of phyllites–quartzites while the overburden consists of recently deposited sediments (Sarris et al., 1998; Vafidis et al., 1996, 2003a,b). These surveys have also shown that archaeological remains at Itanos exist from the surface to a depth of 1–3 m (i.e., some of the subsurface remains exist within the penetration depth of long-wave solar radiation).

The site was therefore chosen for the current study since it contains exposed archaeological remains, has existing detailed

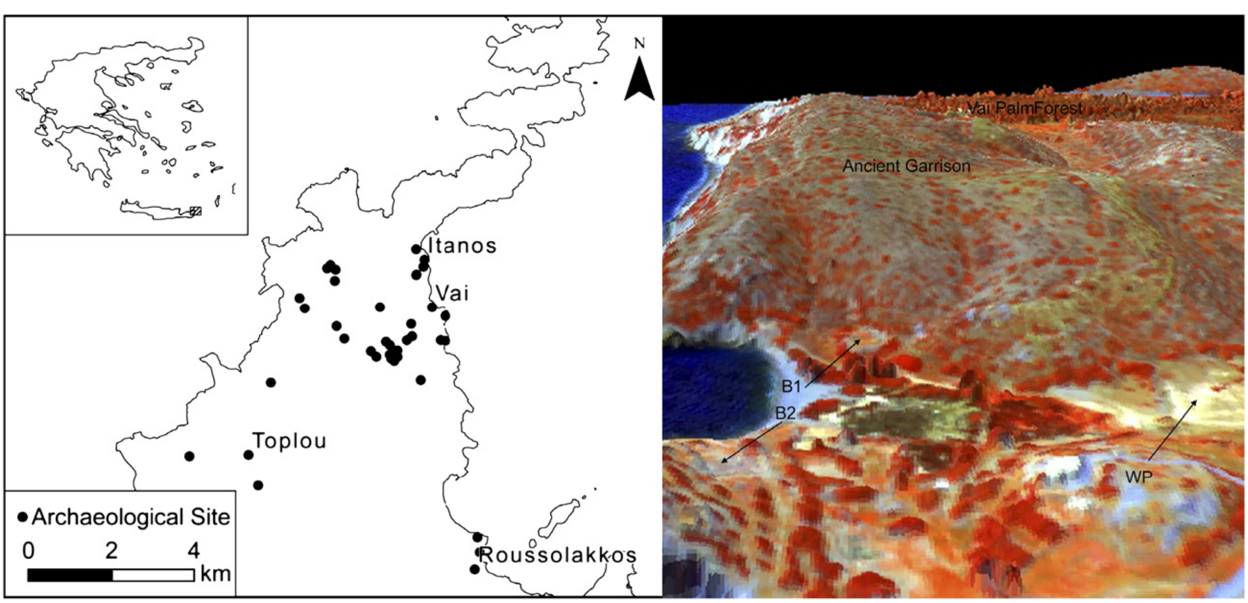

Fig. 1. Map of north-eastern Crete, highlighting the density of known archaeological sites. The image alongside is a three dimensional representation of the Itanos site based on a false colour composite image derived from CASI data draped over the lidar digital surface model. The image view is to the south and highlights the basilicas (B1, B2) and the area investigated as a possible westward extension of the ancient port (WP).

geophysical data locating buried archaeological features within 1–3 m of the surface and has relatively low vegetation densities with areas of exposed soil. The exposed archaeological remains are well conserved and are mainly constructed from local stone. This fact poses a potential problem for remote sensing since their reflectance characteristics are likely to be similar to the surrounding material.

Airborne imagery was acquired over a two-day period in April 2004 as part of the NERC Mediterranean Flight Campaign. Data from two primary sensors, namely the Airborne Thematic Mapper (ATM) and the Compact Airborne Spectrographic Imager (CASI), are considered in the paper together with lidar data and aerial photography acquired as part of the same flight campaign. The CASI sensor is limited to the visible and near infrared (NIR) and was programmed to operate in spatial mode acquiring data in 15 channels from 449 nm to 940 nm at a spatial resolution of 2.0 m, whilst the ATM sensor acquired data in 11 broader bands, with a spatial resolution of 2.5 m. The ATM sensor provides important information in the Short Wave Infrared (SWIR) and the thermal (TIR) portions of the spectrum with respect to soil properties and heat capacity. Lidar, CASI, ATM and aerial photography were acquired at approximately 15:00 hpm on the 17th of April whilst a second series of ATM images were captured at 06:00 h on the 18th of April in order to gauge diurnal heat capacity.

4. Data processing methods

The CASI imagery was converted to units of reflectance based on in situ ground spectral measurements with a GER1500 spectrometer, whilst the ATM data were atmospherically corrected using the FLAASH module incorporating the MODTRAN4 radiation transfer code (Matthew et al., 2000) in the ENVI software. Both were then rectified using the Azimuth Systems AZGCORR programme, which compensates for aircraft position, altitude and ground surface separation, and involved inputting aircraft navigation information as well as a digital elevation model derived from the lidar (AZGCORR, 2005). The lidar data were acquired using an Optech ALTM 3033 high-resolution airborne laser scanner with a point density of 1.0 m, the data from which was initially processed by the Landscape Modelling Unit at the University of Cambridge. Soil temperature profiles were acquired with a series of Skye Instruments sensors coupled to a data logger in an area adjacent to the archaeological site in order to calibrate and interpret the thermal data. Once corrected, derived images were extracted from the remotely sensed airborne data (e.g., the Normalised Difference Vegetation Index, NDVI (Jensen, 1986), which is based on reflectance in the red and NIR portions of the electromagnetic spectrum). Imagery was then integrated, segmented and classified based on an object-oriented approach within the eCognition software (Benz et al., 2004). The imagery was further processed using the Reed–Xiaoli (RXD) unsupervised anomaly detection algorithm within the ENVI software package, which extracts unknown targets that are spectrally distinct from the image background (Kwon et al., 2003). Prior to applying the algorithm shrubs were masked from the process using a combination of the lidar and the NDVI data.

5. Results

The interpretation of imagery will focus on areas within the main excavated archaeological site as well as the ancient garrison wall to the south. A fundamental assumption made at the outset was that both surface and subsurface remains would have distinct spectral characteristics compared with the surrounding material, which can be characterised through the analysis of the visible and/or NIR and/or TIR portions of the spectrum. For this to hold true the results of the field spectrometer study conducted needed to indicate distinct spectral patterns for the major units within the Itanos scene. In terms of the surface archaeological remains at Itanos this is most certainly correct. Distinct differences are observed in the reflectance patterns of the sandstone and grey slabs that make up the remains of the basilica, which contrast favourably with the surrounding soils and vegetation (Fig. 2); a fact that is further demonstrated by the CASI and ATM data. However, it is statistically difficult to relate differences in soil reflectance patterns within the visible and NIR range (i.e., sensed by the GER-1500) to subsurface remains detected by the geophysical survey.

As a consequence, the visible/NIR data alone derived from the CASI and the ATM sensors have successfully mapped the surface remains at Itanos (e.g., basilica walls, Fig. 3). Inevitably, the superior spatial resolution of the CASI data compared to the ATM is advantageous for mapping remains such as the basilica but in general, based on the classification, the higher spectral resolution capability of the CASI does not out perform the ATM in this case.

5.1. Inland extension of the port at Itanos

With respect to shallow subsurface remains, a key issue at Itanos is the possible inland extension of the port. This area has been intensively probed by geophysical techniques, which

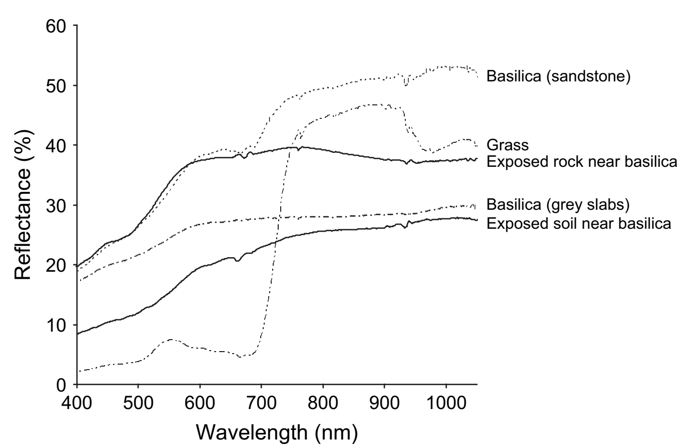

Fig. 2. Reflectance spectra of sub-aerial features adjacent to the northern most basilica (B2) at Itanos, as captured by the GER1500 spectrometer.

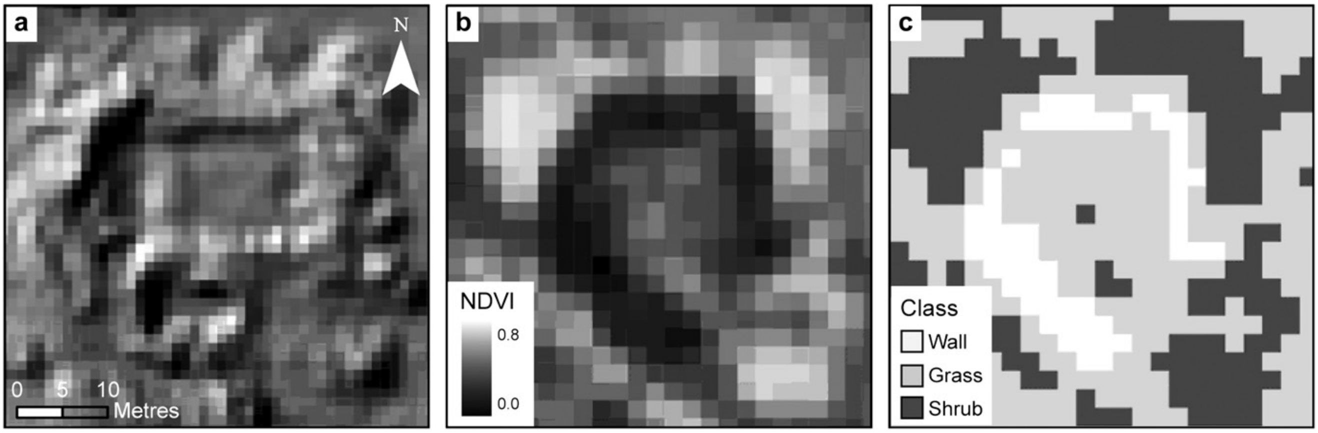

Fig. 3. Series of images of the southern most basilica at Itanos: (a) shaded relief image derived from the lidar data; (b) Normalised Difference Vegetation Index (NDVI) image derived from CASI in order to differentiate between vegetation types (light grey) and exposed stone wall of the basilica (dark grey); and (c) a classified image of CASI and lidar data derived from an object-oriented approach using the eCognition software.

indicated that the top of the bedrock, consisting of eroded phyllites, reaches a maximum depth of 10 m below the current surface (Fig. 4a). The lidar data suggest that the area has no definable topographic variation (Fig. 4b) and the classification of the visible channels of the CASI and ATM sensors do not reveal distinct linear features or anomalies beyond variations in surface vegetation.

The RXD output for the CASI and ATM data are presented in Fig. 4c and d, respectively, and show the level of anomaly on a progressive scale from blue to yellow and red, with red indicating areas of high anomaly. Both images indicate the presence of several anomalies in the upper portion of the subset (e.g., A1–A4); however, many of these are artefacts of shade (e.g., A1) and variations in vegetation cover (e.g., A2). Nevertheless, the images indicate other subtle anomalies that can not be attributed to these categories and are therefore interpreted as being signals of subsurface remains (e.g., A3 and A4) since they correlate with zones where geophysical surveys have identified subsurface remains (Fig. 4a).

5.2. Ancient garrison

The archaeological survey of the site has previously located the presence of a wall running along the hill to the south of the main site. The position of the wall in certain locations is confirmed by the aerial photography, the shade image derived from the lidar data and by the visible channels of the CASI and ATM (Fig. 5a–c, feature W1); however, the wall is not

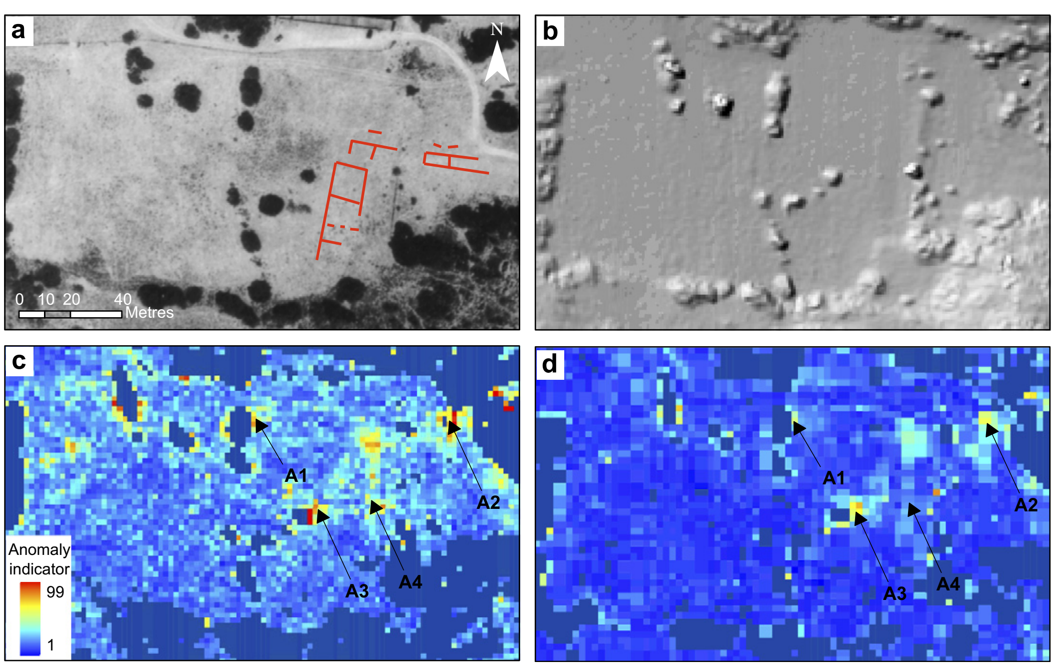

Fig. 4. Series of images focusing on the possible extension of the ancient port to the west: (a) aerial photograph with the location of buried archaeological remains derived from geophysics superimposed; (b) shaded relief image derived from the lidar data; (c) output of the Reed–Xiaoli algorithm for the CASI imagery; and (d) output of the Reed–Xiaoli algorithm for the daytime ATM imagery. Features A1–A4 are highlighted as anomalies (see text for full explanation).

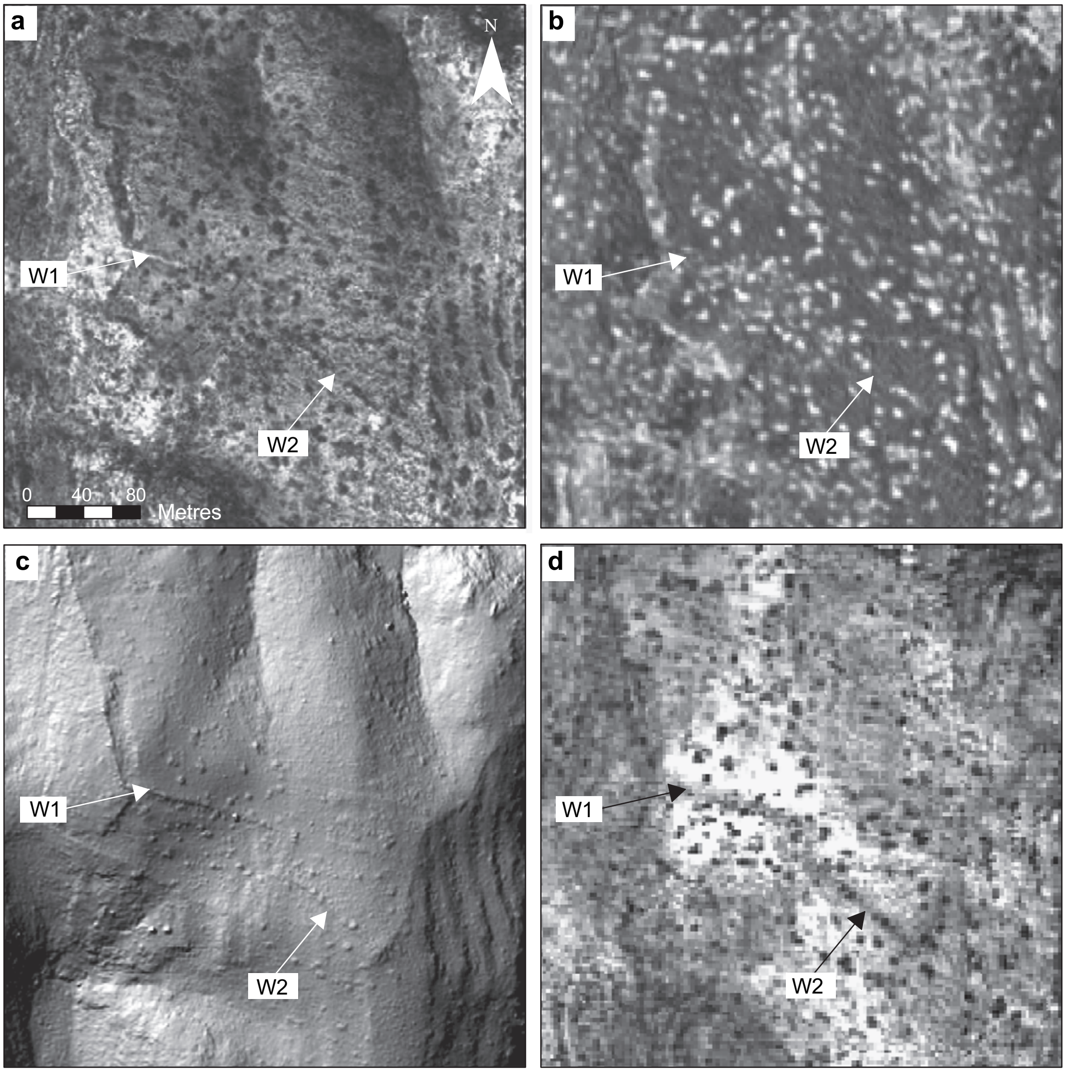

Fig. 5. Imagery focusing on the ancient settlement on the hill to the south of Itanos: (a) panchromatic aerial photograph; (b) NDVI image derived from CASI; (c) shaded relief image based on the lidar; and (d) thermal channel data derived from daytime ATM. Features W1 and W2 relate to the ancient garrison wall (see text for explanation).

continuous. The original wall dates from the early part of the third century BC, and housed the Ptolemaic garrison at the town (Spyridakis, 1986). The fact that the wall is not readily distinguishable in the visible imagery suggests that it is in part found beneath the surface or is masked in other areas by vegetation (Fig. 5b). However, with parts of the feature distinguishable in the shade image (Fig. 5c) it is suggested that, even if covered, parts of the wall retain some of its original height.

This location constitutes the most appropriate test bed for the application of thermal imagery at the Itanos site given that the width and length of the feature is likely to be on a spatial scale appropriate to the ATM imagery. On visual inspection, both the day- and night-time thermal imagery indicate the presence of a more continuous feature than mapped by the original archaeological survey or by the visible reflectance of the CASI and ATM sensors. Point W2 for example represents a location with a noticeable decrease in radiance compared to neighbouring pixels in daytime thermal imagery (Fig. 5d), with a converse pattern in the night-time thermal imagery. Such a pattern is indicative of the presence of the ancient wall. Although complicated by the presence of shrubs, the thermal pattern demonstrates the utility of such data for locating the presence of shallow buried features, especially in areas where the dimensions of the remains are large enough to produce a well-defined contrasting signal to the surrounding material. Again, this largely relates to the distinctiveness of a feature as well as its spatial extent and the spatial resolution of the captured imagery.

5.3. Wider archaeological appreciation

In addition to providing a digital elevation model of the study site for the purposes of geocorrecting the CASI and ATM imagery, the lidar data is valuable in its own right as a source of data for viewshed analysis, feature extraction and in a more subtle manner to interpret the landscape in terms of past activities. In the wider Itanos area, the lidar data has identified the presence of other features of archaeological interest such as abandoned terraces (Fig. 6a, feature T) and a circular depression similar to those found within the archaeological site at Itanos, which has been interpreted to be a threshing floor (Fig. 6b, feature D). By combining multi- or hyperspectral data with a digital elevation or surface model, wider appreciation and interpretation of the landscape is facilitated (Fig. 1). The relationship between different elements of the landscape (e.g., geomorphological features, vegetation and water), which may have contributed to the establishment of the settlement, can be better appreciated through such an approach.

6. Conclusions

Whilst surface archaeology has been well mapped by the various sensors, the delineation of subsurface remains based on remote sensing is problematic, although anomalies have been mapped in zones corresponding to known subsurface remains. Difficulties stem from the presence of outcropping rock, vegetation and mixed pixels in key archaeological areas. The study has shown that multi- and hyperspectral imagery are best employed within a multidisciplinary approach incorporating other remote sensing tools (e.g., ground based geophysical techniques and lidar). A key consideration in being able to determine the presence of both surface and shallow subsurface remains is that the remote sensing takes place at a scale appropriate to the spatial resolution of the objects. The advantage of opting for the high spatial resolution configuration is that data are acquired across the spectral range at a resolution close to the actual spatial patterns of remains such that the likelihood of unmixed pixels is greater. Even so, in this particular case study, a spatial resolution of 2.0 m for CASI and 2.5 m for the ATM was still too coarse to detect potential subsurface remains within the Itanos area. Practical issues resulting from the mountains terrain in the immediate vicinity of the site precluded acquisition of data at a higher spatial resolution.

Future studies would ideally employ sensors that have the highest spatial resolution possible and which have spectral coverage that extends from the visible through into the thermal. Remote sensing can therefore complement geophysical and surface surveys and has the potential of delineating areas for further detailed field-based investigations.

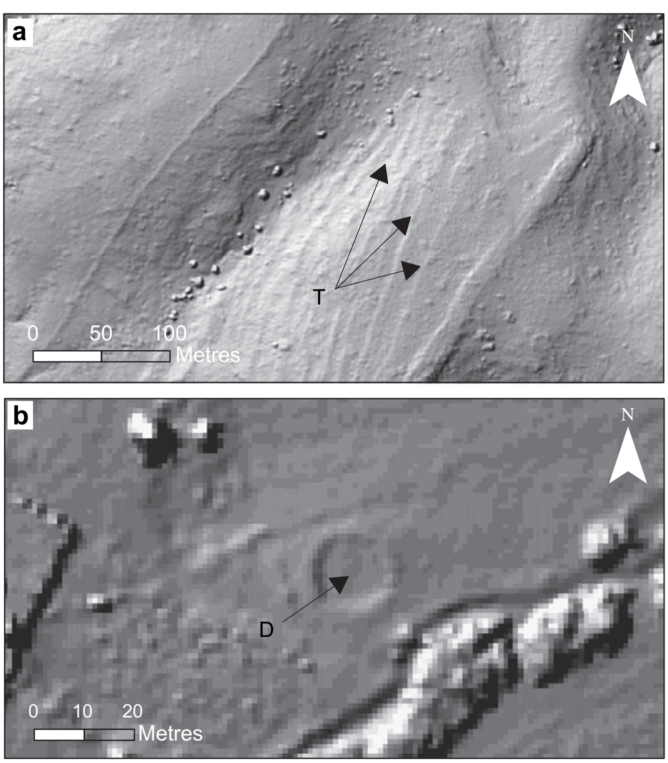

Fig. 6. Shaded relief images based on lidar data of (a) an area south of Itanos highlighting distinct abandoned terraces (T) and (b) the presence of a circular depression (D) south west of Itanos.

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