Active Satellite Sensors for the needs of Cultural Heritage: Introducing SAR applications in Cyprus through the ATHENA project

Demetris Kouhartsiouk[1*], Athos Agapiou[1], Vasiliki Lysandrou[1], Kyriacos Themistocleous[1], Argyro Nisantzi[1], Diofantos G. Hadjimitsis[1],
Rosa Lasaponara[2], Nicola Masini[3],
Ramon Brcic[4], Michael Eineder[4], Thomas Krauss[4], Daniele Cerra[4] , Ursula Gessner[4] and Gunter Schreier[4]

[1] Remote Sensing and Geo-Environment Laboratory, Eratosthenes Research Center, Department of Civil Engineering & Geomatics, Cyprus University of Technology, Saripolou Str. 2-8, 3036 Limassol, Cyprus
[2] National Research Council, Institute of Institute of Methodologies for Environmental Analysis, C.da S. Loya, 85050 Tito Scalo, Italy
[3] National Research Council, Institute of Archaeological and Monumental Heritage, C.da S. Loya, 85050 Tito Scalo, Italy
[4] Earth Observation Center - EOC, German Aerospace Center – DLR, Wessling, D-8223 Oberpfaffenhofen, Germany
* d.kouhartsiouk@cut.ac.cy

Abstract

Non-invasive landscape investigation for archaeological purposes includes a wide range of survey techniques, most of which include in-situ methods. In recent years, a major advance in the non-invasive surveying techniques has been the introduction of active remote sensing technologies. One of such technologies is spaceborne radar, known as Synthetic Aperture Radar (SAR). SAR has proven to be a valuable tool in the analysis of potential archaeological marks and in the systematic cultural heritage site monitoring. With the use of SAR, it is possible to monitor slight variations in vegetation and soil often interpreted as archaeological signs, while radar sensors, depending on the sensor's frequency, have penetrating capabilities offering an insight into the shallow underground remains. Radar remote sensing for immovable cultural heritage and archaeological applications has been recently introduced in Cyprus through the currently ongoing ATHENA project. The project, which runs under the H2020-TWINN-20150Coordination & Support Actions, aims at building a bridge between research institutions of the low-performing Member States and internationally leading counterparts at EU level, mainly through training workshops and a series of knowledge transfer activities, frequently taking place on the basis of capacity development. The project is formed as the consortium of the Remote Sensing and Geo-Environment Research Laboratory of the Cyprus University of Technology (CUT), the National Research Council of Italy (CNR) and the German Aerospace Centre (DLR). As part of the project, a number of cultural heritage sites in Cyprus have been studied testing different methodologies involving SAR imagery such as Amplitude Change Detection, Coherence Calculation and fusion techniques. ATHENA's prospective agenda includes the continuation of the capacity building programme with upcoming training workshops to take place while expanding the knowledge of radar applications on conservation and risk monitoring of cultural heritage sites through SAR Interferometry. The current paper presents some preliminary results from the archaeological site of "Nea Paphos", addressing the potential use of spaceborne radar technology.

1. Introduction

The growing availability of high to very-high spatial resolution Synthetic Aperture Radar (SAR) data has enabled the expansion of the current pool of remote sensing techniques used for archaeological prospection to an abundance of new methods and capabilities. Already, SAR applications in archaeology are becoming increasingly widespread (Agapiou & Lysandrou, 2015) largely driven by the rapid technological developments in the disciplines of space technologies and science.

Fig. 1. The "Nea Paphos" archaeological site.

Nevertheless, the capabilities and potential of SAR technologies have yet to fully assessed, with data processing proving to be a challenging task and the interpretation of results often being complex due to the lack of systematic methodologies (Chen et. al., 2016) .

The current study aims to present a set of preliminary results from the analysis of X-band SAR imagery over "Nea Paphos" archaeological site as part of demonstrating the benefits of SAR imaging solutions for the purposes of archaeological prospection. The study also aims to introduce SAR research in the field of archaeological investigation on a national level.

The data used for the study are initial TerraSAR-X data acquired as part of larger datatake agreement plan between the consortium members for the ATHENA project spanning over one year (from April 2016 to April 2017).

The archaeological site of "Nea Paphos" (34.758292°, 32.406999°) (illustrated in Fig. 1) lies to the southwest coast of Cyprus to the west of the city of Paphos (Fig. 2). "Nea Paphos" is an inscribed site on the World Heritage List of UNESCO.

Although a part of the area has been extensively excavated since the 1960s and a number of archaeological findings being put on display, there is still a large percentage of the site unexploited. This offers an ideal site for studying and applying both passive and active remote sensing techniques for the purposes of archaeological investigation and preservation of cultural heritage. Due to the long ancient history of the area, it is believed that multiple monuments and structures were build on top of each other through the centuries.

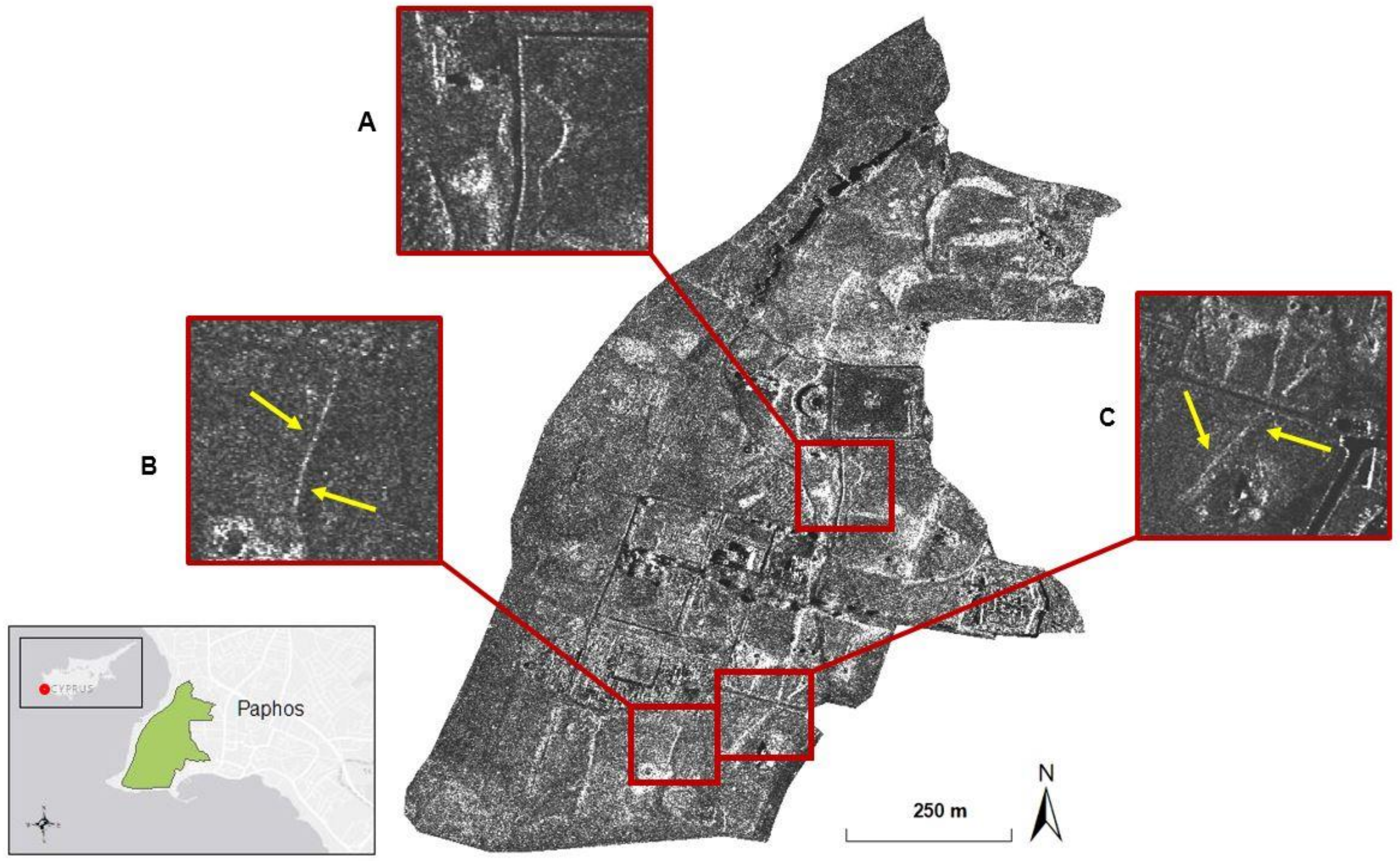


Fig. 2. Geometric features identified in "Nea Paphos" area (shown in green) using SAR imagery. (A) Round feature, (B) Linear features. TerraSAR-X High Resolution Staring Spotlight Mode (0.74m ground pixel spacing) image acquired on the 22 April 2016 at 38.033 degrees of incidence angle by right-looking antenna in descending orbit.

2. Methodology

The basis of the methodology employed is a single and multi-temporal analysis of surface signs (vegetation and soil marks) as a function of varying Incidence angle information and orbit direction (descending / ascending) and through the analysis of changes in backscatter signal and radar phase information.

The analysis was based on the detection of abnormal backscattering effects compared to the optical surface information as well as on the detection of geometric shapes based on different radar pulse illumination conditions. Pairs of SAR images were also analysed for detecting spatial and temporal changes in the backscattered radar signal. The method, known as Amplitude Change Detection, enables the computation of ratios between SAR pairs as indication of changes in surface texture. For X-band frequency radar, changes in vegetation cover and growth can be examined along with changes in soil moisture.

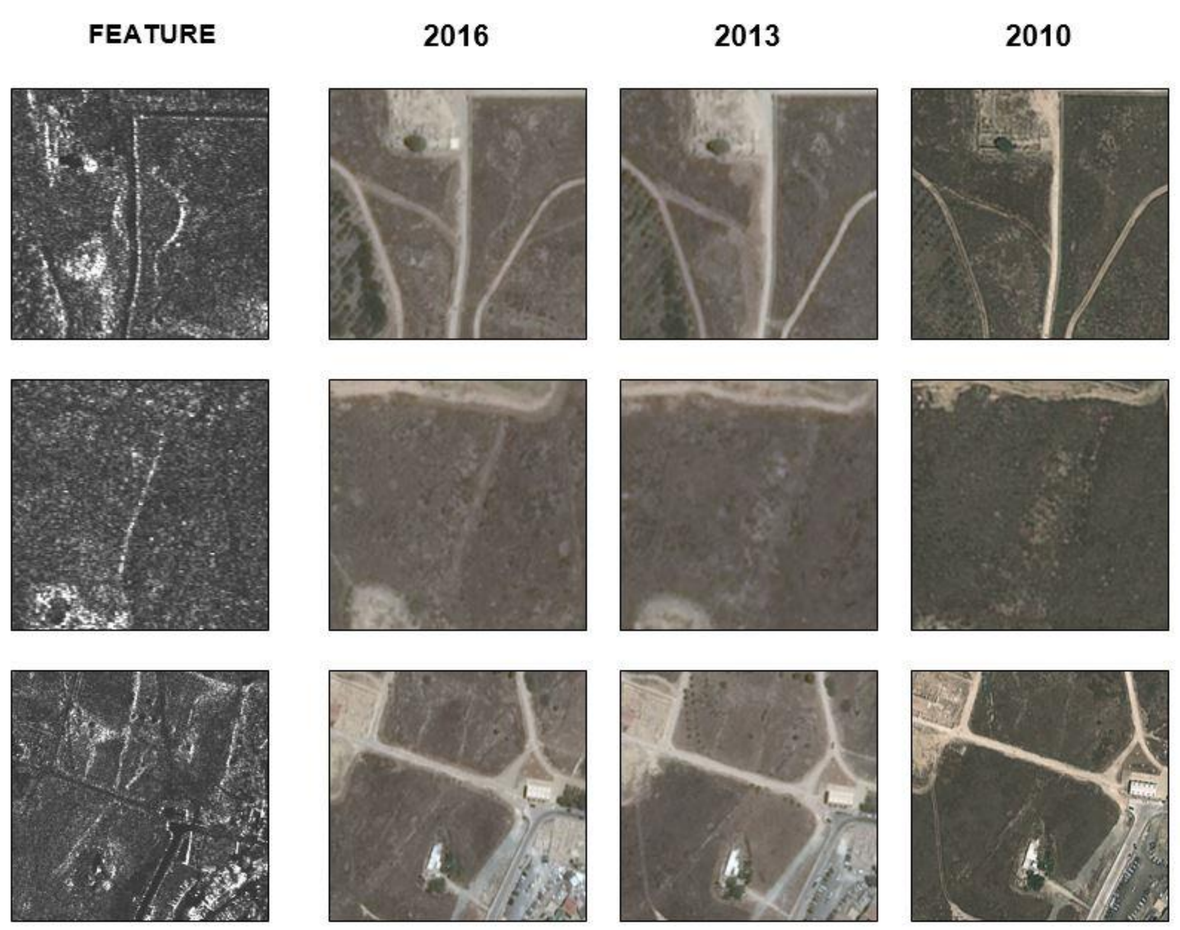


Fig. 3. Temporal comparison of the geometric features identified in "Nea Paphos" area (Figure 2) with RGB images.

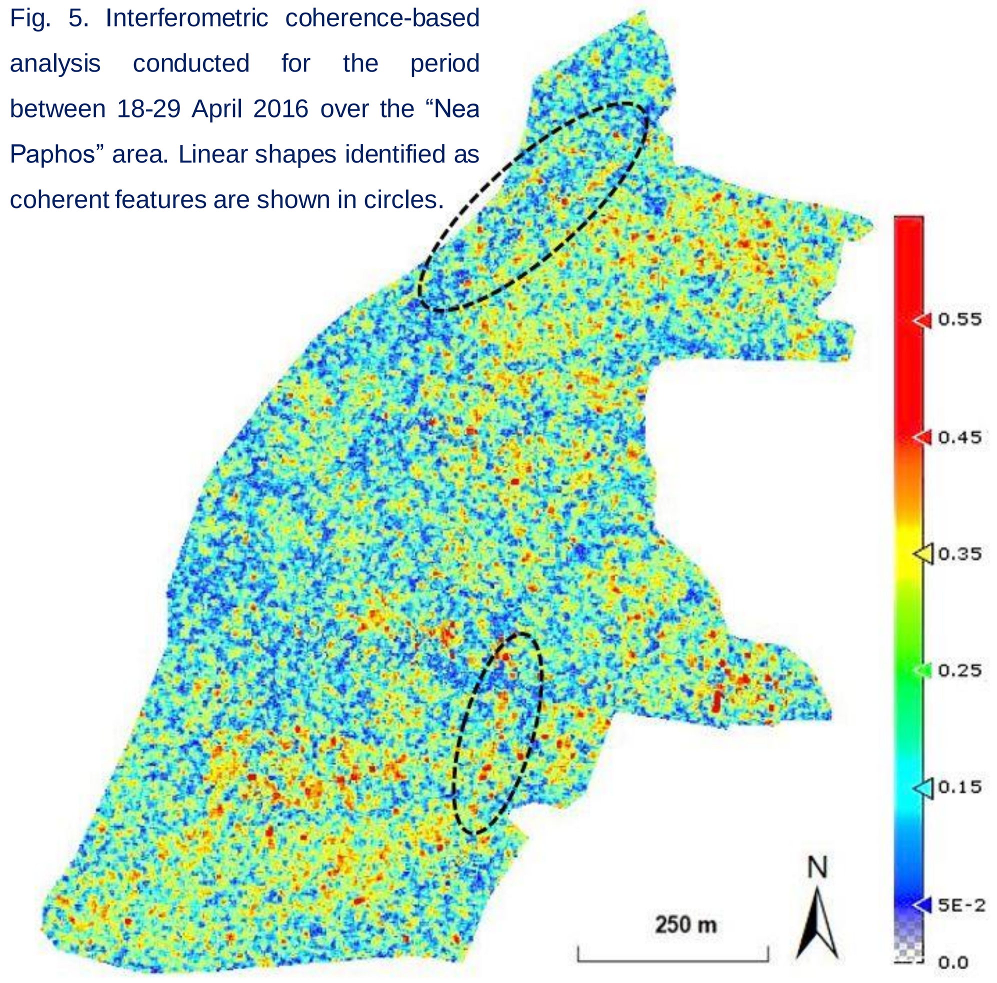
3. Results

A number of geometric features were identified following the shadow and ground relief analysis of low (28°), moderate (38°) and high incidence angle (58°) images (EEC & ground range corrected SSC) of different orbit directions (descending and ascending). The identified shapes were compared against optical imagery over a temporal span of 6 years. Features include round and linear shaped outlines, suggestive of wall structures. The geometry of the features was found to be closely dependent upon the incidence angle and even more importantly by the satellite flight path i.e. orbit mode – descending / ascending. The linear features were only detectable when parallel to the flight path and the antenna looking direction and field of view was not obstructed i.e. in low incidence angle.

4. Discussion - Change Detection

Fig. 4. Amplitude Change Detection (18-29 April 2016) based on the ratio of the backscattering coefficient using TerraSAR-X SSC ST geometrically corrected to ground range images (yellow – no change in backscatter, green - increased backscatter) (A). RGB Image showing corresponding areas of minimum change in backscatter intensity (B). RGB Image showing the outline geometrical patterns of the features identified (C).

Fig. 5. Interferometric coherence-based analysis conducted for the period between 18-29 April 2016 over the "Nea Paphos" area. Linear shapes identified as coherent features are shown in circles.



The analysis of the changes in amplitude and phase provide an insight into the soil and vegetation responses to potentially underlying buried structures. Generally, both the amplitude and coherence derived help emphasize additional potential archaeological remains, which exhibit minimum surface relief backscatter i.e. indistinguishable via traditional shadow and geometric analysis but are largely governed by soil characteristics and vegetation. To support the current findings and further expand on them, the results will be compared to multispectral vegetation indices

Conclusions

In this study, the potential of SAR remote sensing in archaeological prospection was assessed through the presentation of a set of preliminary results from the "Nea Paphos" area. A number of geometric features were identified as potential buried archaeological structures. Examination of the vegetation and soil marks using amplitude and coherence change detection techniques allowed the detection of additional geometric shapes as potential archaeological remains. As part of the prospective of the ATHENA project, additional techniques using SAR imagery are planned, conducting a time-series analysis of the soil and vegetation marks as archaeological proxies (dataset spanning over a year) and making use of Differential interferometry (DlnSAR) for studying surface microrelief and risk mapping of cultural heritage sites.

References

Chen, Fulong, Masini, Nicola, Liu, Jie, You Jiangbin & Lasaponara Rosa. "Multi-frequency satellite radar imaging of cultural heritage: the case studies of the Yumen Frontier Pass and Niya ruins in the Western Regions of the Silk Road Corridor." *International Journal of Digital Earth* 9.12 (2016): 1224-1241.

Agapiou, Athos, & Vasiliki Lysandrou. "Remote sensing archaeology: Tracking and mapping evolution in European scientific literature from 1999 to 2015." *Journal of Archaeological Science: Reports* 4 (2015): 192-200.

....more info

www.athena2020.eu

Acknowledgments

"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691936".