Active Satellite Sensors in Cultural Heritage Research: The Use of SAR for Archaeological Prospection

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Abstract This paper provides an overview on the application of satellite synthetic aperture radar (SAR) technology in archaeology. The growing developments of space SAR technologies in terms of observational capabilities (spatial, spectral, radiometric, and temporal coverage) had made the use of these technologies very attractive for archaeological investigations. Although several achievements have been made in recent years on the basis of pioneering efforts addressed to the assessment of the potentiality of the L-, C-, and X-band SAR in archaeology, the full capability of these technologies for archaeological site detection is still incompletely evaluated until now. Moreover, significant advances are expected from the most recent satellite data available at 25 cm in X-band (TerraSAR) and at 1 m in multipolarized L-band (PALSAR). These enhanced characteristics, in terms of spatial resolution and radiometric quality, take the most recent SAR technologies to a new level for archaeological applications, addressed to object detection and target recognition.

Keywords Synthetic aperture radar · Archaeological mark · Satellite · Metaponto · Sabratha

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Introduction

Nowadays, the increasing availability of active and passive satellite sensors that provide very high-resolution data has opened new opportunities, unthinkable only a few years ago (Lasaponara & Masini 2008). The space technologies today available can provide extremely precise results for archaeological applications speeding up the work during the diverse phases of investigations ranging from survey, mapping, excavation, documentation, exploitation, and monitoring. Moreover satellite sensors offer data and information at diverse scales of interest, moving from small artefacts to architectural structures and landscape reconstruction. It is also possible to integrate ancient environment reconstruction, obtainable from space, with the mapping of past (even buried) and present (emerging) settlements and landscapes.

Synthetic aperture radar (SAR), in comparison with optical approaches, is an innovative microwave remote sensing technology characterized by penetration, polarization, and interferometry.

Satellite synthetic aperture radar (SAR) has entered into a golden age with a rich availability of data from both historical archives and numerous operative satellite platforms, which, compared to the past, offer advanced imaging mode capabilities available in diverse bands (L, C, and X). Moreover, the currently available satellite SAR systems provide data with a greater flexibility in the selection of incidence angles and polarizations, even in the scale of 1 meter and less. These advanced technical characteristics make the use of SAR data very attractive for numerous application fields, including archaeology (Lasaponara and Masini 2013; Chen et al. 2017).

The use of SAR data in archaeology can offer great potential for site detection (buried or emerging archaeological remains) and monitoring. Moreover, SAR enables us to overcome some limitations of optical imaging providing all weather acquisitions, at any time of day or night, also capable to "penetrate" (to some extents) vegetation and/or soil, depending on the antenna wavelength, surface characteristics (ice, desert sand, close canopy, etc.), and conditions (moisture content) (Wisemann and El-Baz 2007).

Even if the early applications of radar for archaeological purposes date back to the 1980s, later the use of SAR was historically limited by the low spatial resolution of the early sensors, as well as by the limited public availability of data and the complexity of data processing. This was and still is particularly relevant for archaeological investigations focused on the detection of subtle signals, often covered by noise, and only detectable in specific conditions depending on soil characteristics, moisture content, vegetation phenomenology, etc. The early applications of radar undoubtedly enabled numerous important archaeological discoveries and provided new insights in vast deserted areas, as in the case of the Sahara (McCauley et al. 1982). Nevertheless, the use of radar on both aerial and space platforms was mainly based on a few demonstrative experimentations made by NASA researchers, but, definitely, they were strongly limited for "operative" investigations. This means that, still today, there is a significant lack of studies and investigations conducted using SAR for archaeological purposes.

The availability of very high-resolution satellite radar data such as TerraSAR-X and COSMO-SkyMed, launched in 2007, as well as PALSAR L-band, launched in 2014, has opened a new era. Even if the use of satellite radar in archaeology is still in its experimental stage, it, undoubtedly, offers great potential for manifold applications ranging from the detection of features and sites, reconstruction of palaeolandscape, documentation and monitoring of cultural heritage for site enhancement and preservation, etc.

One critical aspect, particularly pressing in archaeology and palaeoenvironmental studies, is still today linked with data processing issues, interpretation, and modeling approaches which should be adjusted or developed ad hoc for archaeological purposes as well as the lack of investigations in different archaeological environments.

A Brief Overview of Satellite Radar Missions

The early 1980s and 1990s were characterized by an intense experimentation of SAR systems. The USA launched four SAR demonstration missions designated as SIR (shuttle imaging radar): SIR-A (1981), SIR-B (1984), and two SIR-C/X-SAR (1994) with simultaneous acquisitions in L-, C-, and X-bands (see https://directory.eoportal.org/web/eoportal/satellite-missions/s/sir-a). European, Russian, Japanese, and Canadian space agencies launched a number of spaceborne SAR missions, such as (ERS)-1, ALMAZ-1, PALSAR/ALOS, and RADARSAT-1.

Later, in 2000 the NASA launched the Shuttle SAR Topography Mission (SRTM) designed for interferometric applications and for measuring large-scale surface changes. Digital elevation model (DEM) from SRTM data, today available at 30 m pixel resolution free of charge for almost 80% of the Earth's surface, has been and still is one of the most useful and used SAR-based products in archaeology and landscape studies.

The advent of the "2000" generation of spaceborne SAR sensors, such as ENVISAT/ASAR (2002–2012, C-band dual), ALOS/PALSAR (2005–2011, L-band), SARLupe (2006, X-band), COSMO-SkyMed (2007, X-band dual), TerraSAR-X (2007, X-band quad), and SARSAT-2 (C-band quad, 2007), provided advanced data acquired with greater flexibility in acquisition angles and polarization modes.

The launch on April 03, 2014, of Sentinel-1 started "the free availability" of SAR data (Berger and Aschbacher 2012). Sentinel-1, based on a long-standing heritage from the ERS, ENVISAT, and RADARSAT missions, operates in C-band and offers two acquisition modes (StripMap and Extra Wide Swath) with the possibility to sense data up to 5 × 5 m resolution (see Table 1).

Finally, ALOS-2, launched on May 24, 2014 with onboard PALSAR-2, opened a new era providing full polarization and high-resolution data in L-band (http://www.eorc.jaxa.jp/ALOS-2/en/about/palsar2.htm).

Table 1 SAR system parameters

SAR system	Band	Polarization	Incident angle (°)	Resolution (m)	Swath width (km)	Organization	Altitude (km)	Orbit Inclination (°)	Launch year
SEASAT	L	HH	23	25	100	NASA	790	108	1978
SIR-A	L	HH	45	30	50	NASA	225	57	1981
SIR-B	L	HH	20–60	30	50	NASA	225	57	1984
ALMAZ-1	S	HH	30–60	15	20–45	RSA (PKA)	300	72,7	1991
ERS-1	C	VV	24	25	100	ESA	790	97,7	1991
JERS-1	L	HH	35	18	76	NSDA/MITI	568	97,7	1992
SIR-C	C,L	All	17–60	25	15–100	NASA	225	57	1994
X-SAR	X	VV	17–60	25	15–40	DLR/ASI	228	57	1994
ERS-2	C	HH	24	25	100	ESA	785	97,7	1995
SARSAT	C	HH	17–50	10–100	50–170	CSA	790	98,6	1995
PRIRODA	S, L	HH	35	30	120	RSA/DLR	394	51,6	1995
ENVISAT	C	All	20–45	30	50–400	ESA	800	100	1998
SRTM	C	HH	20–60	30	60	NIMA/NASA	233	57	2000
PALSAR	L	HH; VV HV; VH	20–55	10–100	70–250	NASDA/ MITI	700	98	2002
Light SAR	L	All	20	25–100	50–500	NASA	790	97,7	2003
COSMO-SkyMed ScanSAR	X	One and two polarization modes (HH, VV, HV, or VH)	20–59	16–100	100–200	ASI	620	97,8	2007
COSMO-SkyMed StripMap	X		20–59	3–20	30–40	ASI	620	97,8	2007
COSMO-SkyMed Spotlight-2	X		20–59	1	10	ASI	620	97,8	2007
TerraSAR-X StripMap mode	X	(HH/VV), (HH/HV), VV/VH)	15–60	1.55–3.21	15–30	DLR- ASTIRUM	514	97,44	2007

TerraSAR-X spotlight mode	X	(HH,VV), (HH/VV)	15–60	1.34–3.21	10	DLR-ASTIRUM	514	97,44	2007
TerraSAR-X ScanSAR mode	X	HH, VV	15–60	1.55–3.21	100	DLR-ASTIRUM	514	97,44	2007
Sentinel-1 Strip Map	C	VV + VH HH + HV HH VV	20–45	5	80	ESA	693	98,18	2014
Sentinel-1 Interferometric Wide				5 × 20	250				
Sentinel-1 Extra Wide				20 × 40	400				
Sentinel-1 Wave Mode				5	20				
PALSAR-2 spotlight	L	HH, VV, HV	8–70	1–3	25	JAXA	636–639	97,92	2014
PALSAR-2 StripMap		HH, VV, HV (HH + HV), (VV + VH) (HH + HV + VV + VH)		3/6/9	50–70				
PALSAR-2 ScanSAR		HH, VV, HV (HH + HV), (VV + VH)		100	350–490				

Satellite SAR Technologies in Archaeology

In the past, archaeological research based on satellite SAR data was constrained by low-resolution as well as complexity of data processing and interpretation. Today, abundant high-resolution, multimode satellite SAR, i.e., TerraSAR-/TanDEM-X, COSMO-SkyMed, RADARSAT-2, and ALOS PALSAR-2, as well as SAR data that are cost-free (Sentinel-1 from the European Space Agency) are available due to the technology development for acquiring multimode data. SAR data for archaeology definitely could step into a golden era; but applications still face challenges due to the lack of systematic methodologies for acquiring and interpreting data. For example, compared with optical approaches, performance of SAR data for archaeological applications is not fully understood and needs exploitation for further advancing the use of the technology.

The first applications of SAR in archaeology were made in desert areas by exploiting the penetration capability of the first shuttle imaging SIR-A. Herein we highlight the main results achieved such as the discovery of the palaeochannels in the desert area of northern Sudan and Southern Egypt (McCauley 1982; El-Baz 1998) and the buried river system in the Taklamakan (Holcomb and Shingiray 2007). Moreover, Mayas' ancient irrigation canals were discovered using SEASAT data in the Yucatan Peninsula (Adams 1980; Adams et al. 1981; Pope and Dahlin 1989).

The Lost City of Ubar was discovered in the desert of Oman by Blom et al. (1997). Sections of the ancient Great Wall of the Sui and Ming dynasties were identified by Guo (1997) using multiband and multi-polarization SIR-C/X-SAR data (Guo 1997). Settlements and river systems in the lower Mesopotamian Plain (Nippur archaeological sites in Iraq) were investigated by Richason III and Hritz (1998) using the Canadian SARSAT data.

In the 2000s, the easier (compared to the past) access to archive data and the availability of high-resolution data increased the interest in the use of spaceborne SAR in archaeology as evident by the publication of a dedicated book (Wiseman and El- Baz 2007) and a special issue in *Archaeological Prospection* (Lasaponara and Masini 2013). Inside this special issue, the archaeological landscape in the Nazca desert (Southern Peru) was investigated by Cigna et al. (2013) using ENVISAT C-band advanced SAR (ASAR). The archaeological site of Pelusium in the desert area of the northeastern edge of the Nile Delta (in Egypt) was investigated by Stewart et al. (2013) using multitemporal PALSAR data. A comparison between TerraSAR data and georadar survey conducted at a test site of a Roman fortress in Syria was made by Linck et al. (2013) in order to assess the penetration capability of the X-band in desert areas.

The quality and accuracy of TanDEM-X digital elevation models were specifically evaluated by Erasmi et al. (2014) for some archaeological sites in the Cilician Plain, Turkey. These analyses enabled the authors to identify and map palaeochannels in the investigated alluvial plain of Cilicia. Significant advances in SAR based investigations in presence of vegetation cover have been achieved by (Jiang et al. 2017; Stewart (2017). Jiang et al (2017) devised a model to use crop-marks as proxy indicators in SAR imaging in Luoyang (China). Stewart (2017) demonstrated that SAR backscatter intensity, coherence and interferometry can be used to identify archaeological residues in vegetated areas over a number of areas in the vicinity of Rome. In desert environment, Comer et al. (2017) used in an integrated way the L-band data acquired by UAV NASA platform with C-band acquired by satellite sentinel-1 satellite to detect and measure landscape disturbance of Nasca geoglyphs. Finally, in oasis ecological niche X- and L-Band SAR Data proved to be effective in detecting palaeoenvironmental features related to ancient cultivations systems in China (Zhu et al. 2018).

It is undoubtedly that the improved observational capabilities of satellite SAR data opened new research lines; among them is the "radar archaeology," namely, the detection of archaeological marks (Chen et al. 2015), herein discussed in section "Radar Space View of Archaeological Marks."

Radar Space View of Archaeological Marks

A correct identification and interpretation of archaeological marks on the basis of radar images is not a straightforward task and requires knowledge about ground surface conditions as well as about the interaction mechanisms between radar waves and surface sensed. It is important to consider that there are significant differences between the interpretation of microwave and optical images including the radar penetration capability. Actually, from the historical points of view, as discussed in section "Satellite SAR Technologies in Archaeology," one of the main important applications of SAR data for archaeology has been focused on the exploitation of radar penetration capability particularly significant in drought desert areas. Compared with optical imagery, penetration is one of the main merits of SAR remote sensing for archaeology. This capability is useful for detection of relics in rainforests and buried remains (settlements and ancient water systems) in deserts. The depth of penetration depends on the wavelength (the longer the wavelength, the deeper penetration), as well as on surface properties (roughness and moisture content) and imaging geometry. Until today, the lack of high-resolution data with greater penetration capability (i.e., L-band) has limited the use of SAR data in archaeology. The recent launch of ALOS-2, with onboard PALSAR-2 operating in L-band and capable to acquire at higher resolution (1×3 m per pixel in spotlight mode), can open encouraging perspectives.

The reconnaissance of typical archaeological marks (such as crop, shadow, and soil/damp marks) by using radar is more complex with respect to optical imaging due to a greater number of parameters that characterize SAR data, including the following:

(i) Characteristics of the radar system such as operating frequency, polarization, angles, viewing geometry (ascending or descending), etc.

(ii) Characteristics of the surface, in terms of land cover type, topography, relief, dielectric constant, moisture content, and conductivity
(iii) Archaeological features in terms of buried or emerging remains, their geometric structure, orientation, building material, etc.

Many of these characteristics or parameters are closely interrelated so that the brightness of features and in turn the visibility of archaeological marks is usually linked to several variables.

The parameters that have a key role in the interactions between radar and target are (i) surface roughness, (ii) radar viewing and surface geometry relationship, and (iii) moisture content and dielectrical properties of the target.

The roughness is usually the dominant factor in a radar picture, but it is very important to consider that it is not an absolute characteristic but it depends on the wavelength and on the incidence angle of radar signal which is another crucial parameter. As a general role, for the same target in the same conditions, there are significant variations of backscattering by changing the incidence angle of the illuminating wave.

One more very important parameter is moisture content which strongly affects the electrical properties of soil, and therefore, it influences the absorption, transmission, and reflection of microwave energy. Generally, radar image brightness tends to increase with the increasing of moisture content (Cigna et al. 2013; Jiang et al. 2016). The acquisition of SAR data in different polarization modes can help in discriminating and estimating the different contributions due to (i) moisture content and (ii) roughness.

On the basis of the previous physical basis consideration, we can argue that, in radar data, the detection of *crop marks, soil marks*, *and shadow marks* (viz., microtopographic relief) is strongly conditioned by the acquisition frequency, view geometry (incidence angle), and moisture conditions.

In optical images, *crop marks* linked to the presence of buried walls and/or filled ditches in vegetated areas produce local variations in moisture and nutrient content and, consequently, in the growth of vegetation that can be revealed by spectral variations in specific spectral channels more sensitive to vegetation (as near infrared) or spectral indices (i.e., mathematical combinations of different spectral channels) as NDVI, etc. In radar data, the understanding and modeling of the interaction radar/surface in the case of crop marks is much more complex compared to optical image due to the great number of factors and interaction mechanisms which affect the backscattering. A promising approach is based on the multitemporal amplitude data processing particularly when SAR image acquisition covers an entire plant growth cycle (Stewart et al. 2013; Chen et al. 2015; Stewart 2017). However, single data analysis can provide good results with the use of adequate filtering methods. In this case, as for optical images, it is important to select data acquired in the most favorable period for crop-mark observation.

In optical images, *damp marks* that occur when archaeological deposits induce local changes in the drainage capability of the soil can be revealed by spectral variations in specific channels more sensitive to moisture or spectral indices (i.e., mathematical combinations of different spectral channels as NDWI, etc.). In a radar image, the changes in moisture content induce variations in the dielectric property of the soil and consequently in the scattering of radar signal. In this case, as for optical image, it is important to select data acquired in the most favorable period, and single data analyses can provide good results with the use of adequate filtering methods. From a theoretical point of view, damp marks should be enhanced by specific polarization (or combination of polarization) more sensitive to moisture.

Finally, regarding *shadow marks,* it should be considered that in optical images, micro-/medium-*topographic relief* linked to archaeological remains, such as earthworks, platforms, ditches, and shallow remain, can be revealed by the presence of *shadow*. In radar data, only very steep slopes cause shadows which are generally not linked to archaeological remains. From the theoretical point of view, *microtopographic relief* linked to archaeological remains should be easier detected using SAR data acquired in X and C bands. In this context, previous experiences of the authors in sites located in Peru and Northern Africa confirmed that the use of COSMO-SkyMed was very effective for the identification of emerging archaeological remains. In this case, shapes and geometric patterns can also facilitate the interpretation of surface roughness as potential archaeological patterns.

As a general rule, the discriminability of archaeological marks is a complex issue linked both to the signal-to-noise ratio and to the differential scattering behavior between target/feature and its surrounding. Some recent applications suggest a strategy based on the use of (i) adequate filtering techniques, (ii) multitemporal data processing, including coherence and interferometry (Stewart 2017) and (iii) knowledge of the problem/site to select the best data and period of observation (Chen et al. 2015)

Practical Examples of Archaeological Marks Detection Based on Radar Data

Microtopography as Archaeological Proxy Indicator: the Case of Sabratha

The second study area is the archaeological site of Sabratha, on the coast of Libya (Fig. 2 upper left), 64 km west of Tripoli, characterized by an arid climate in a desert environment.

Sabratha was founded in the seventh century BC by the Phoenicians of Tyre in one of the few natural harbors of Tripolitania and soon became a trading post at the mouth of a major caravan route (Matthews and Cook 1957). Because of its strategic location, Sabratha experienced a rapid development and soon fell under the control of Carthage. Passed briefly to the Kingdom of Numidia under Masinissa, Sabratha was later taken by the Romans in 46 BC, under which it enjoyed a new prosperity. The city was rebuilt under Roman period when it achieved its greatest prosperity

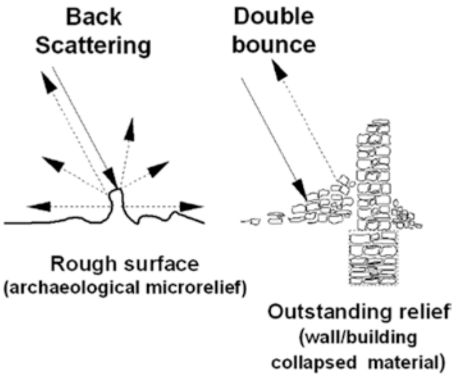

Fig. 1 Interaction between radar and some typical archaeological features

during the second and third centuries AD. Later the city was negatively affected by religious quarrels which probably induced also a decline in the commerce activities, and later on it was destroyed by an earthquake in AD 365. The rebuilding activities were only carried out for a smaller area. In 455 Sabratha was invaded by Vandals, later reconquered by Byzantine and definitively abandoned after the Arab invasions (seventh to eleventh centuries).

The processing and interpretation of remote sensing data focused on an area of about 3 Ha between the Roman town and the amphitheater which is characterized by lesser known archaeological features. They consist of microrelief attributable to shallow remains (walls, foundation) close to the Sabratha amphitheater.

These features are well visible from the COSMO-SkyMed spotlight scene acquired on 12 December 2012 (see Fig. 2b), thanks to the high resolution of the image and the effect of double bounce in backscattering as shown in Fig. 1. The same microrelief could be observed from a multitemporal image set available from Google Earth. However, compared with the spotlight image, the visibility of microrelief is reduced in three of them (10.2009, 20 August 2011, 26 May 2012), and a significant improvement of the spotlight scene in terms of the visibility of archaeological microrelief was achieved using some filtering methods to reduce noise and to enhance the microreliefs of archaeological interest (Chen et al. 2015).

Crop and Damp Marks: Metaponto

The archaeological site of Metapontum is located between the Basento and Bradano rivers, near the Ionian Sea. It has the typical Mediterranean climate. In the Corinne land cover maps, the investigated area is classified as arable with prevailing wheat cultivations. It is one of the most important archaeological areas in the south of Italy. Several archaeological campaigns (Adamesteanu 1973; Carter 1990) have established human presence there since the mid-eighth century BC, when Metapontum was founded by Greeks coming from the Achaea region. Between Greek colonization (700 BC to 200 BC) and the Roman age (200 BC to 400 AD),

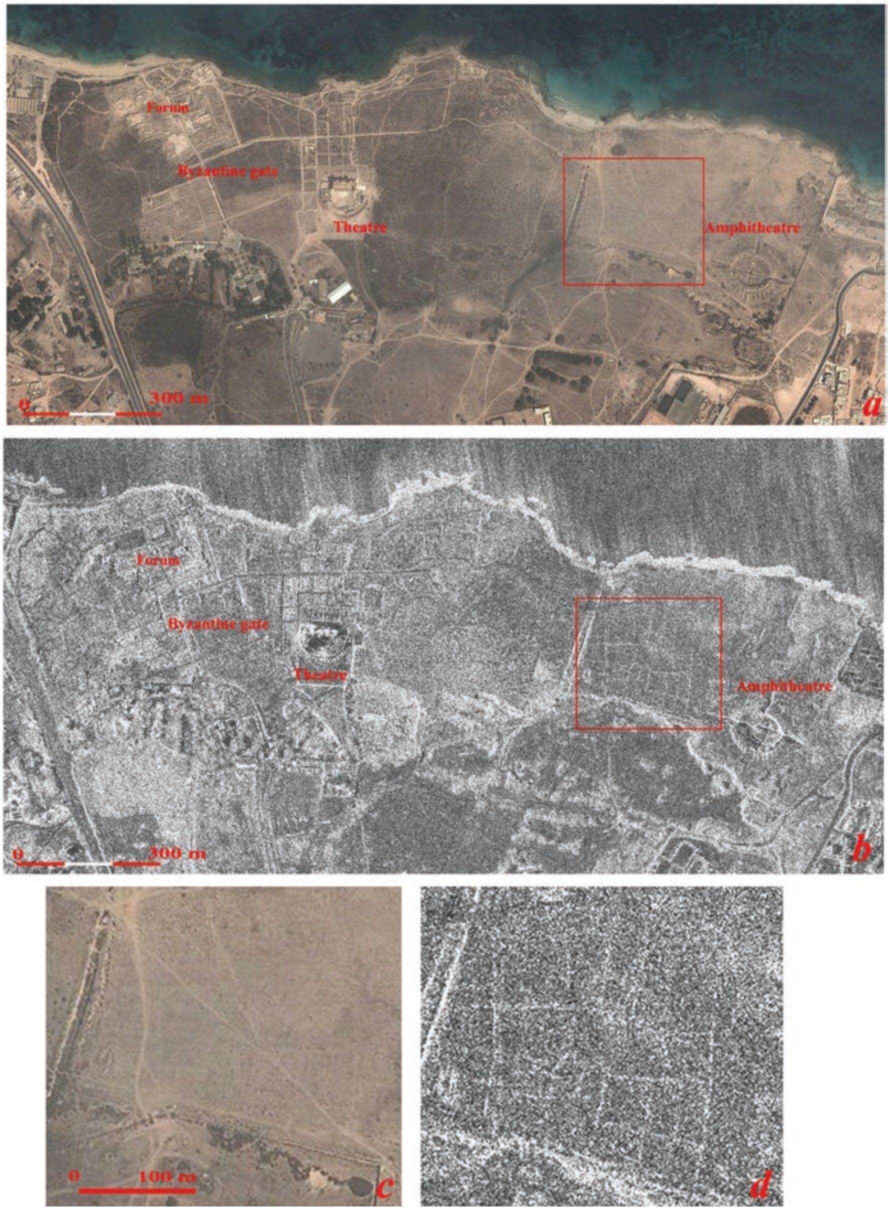

Fig. 2 The archaeological site of Sabratha: comparison between of satellite optical and SAR images (**a** and **b**, respectively). The zooms on an area near the amphitheatre evidence the added value of SAR (**2d**) data respect to optical one (**2c**) in terms of visibility of archaeological features linked to shallow remains.

Fig. 3 Multitemporal imaging of a palaeo-riverbed in Metapontum. (**a**, **b**, **c**) RGB imagery acquired on 22.09.2004, 11.08.2006, and 8.05.2013 (Google Earth courtesy). (**d**) Cosmo SkyMed (Enhanced Spotlight) acquired on 14.11.2011. The visual comparison evidences a better visibility of the palaeo-riverbed from SAR (**d**) respect to optical data (**a**–**c**)

the territory was characterized by an intensive use of soil as revealed by the several rural sites that can be observed from surface surveys and excavations and also the presence of an extensive system of parallel land divisions (Adamesteanu 1973; Carter 1990). Another important element in the history of Metapontum is the spatial and temporal relationship between the hydrography and the human settlements. The rivers Bradano and Basento between which Metapontum is located changed their floodplains several times, influencing the settlement pattern. These spatial features linked to ancient human transformations of the landscape represent one of the most significant traces of ancient human activities which need to be protected. Unfortunately, due to the destructive effects of mechanized agriculture, these traces of the human and geological past are increasingly difficult to identify using solely optical images. For this reason, it has been decided to also use SAR data, such as COSMO-SkyMed acquired in enhanced spotlight mode, in order to assess their ability to detect archaeological and palaeoenvironmental features, in particular roads, palaeoriverbeds, and palaeochannels (see Fig. 3a–d).

In particular, a number of features related to palaeochannels, palaeoriverbeds, ancient roads, and land divisions were investigated. They are very clearly visible from the available COSMO-SkyMed spotlight image processed using (as also for Sabratha) filtering methods to reduce noise and to enhance the microreliefs of archaeological interest (Chen et al. 2015).

Conclusions

This paper offers a brief note to orientate archaeologists in the use of radar technology for applications aimed at identifying the typical marks of archaeological interest (crop, soil, damp, and shadow marks).

A brief history of the use of satellite radar in archaeology coupled with an overview of current satellite missions with main technological characteristics is presented. A correct identification and interpretation of archaeological marks on the basis of radar images is not a straightforward task and requires knowledge about ground surface conditions as well as about the interaction mechanisms between radar waves and surface sensed. It is important to consider that there are significant differences between the interpretation of microwave and optical images including the radar penetration capability.

Firstly, archaeological sites with regular and observable topological traces on the landscape, e.g., crop, shadow, soil, and damp marks (Lasaponara and Masini 2013; Chen et al. 2015), create anomalies on the images, implying the potential of remote sensing for archaeology, particularly when high-resolution SAR data, e.g., TerraSAR-/TanDEM-X, COSMO-SkyMed, RADARSAT-2, and ALOS PALSAR-2, are used. Archaeological features, such as unknown palaeochannels buried under the desert, can be detected by SAR data taking advantage of SAR's penetration capability. In general, penetration is stronger as radar wavelength and subsurface porosity increase. In view of the complicated scenario, the quantitative penetration depth of SAR data however needs to be further estimated through a sufficient number of case studies.

Scaling effect related to the resolution of SAR images is another scientific issue. The optimization of image scaling contributes for cost savings and for improving detection performance in archaeological applications; for example, moderate-resolution SAR data are suitable for large-scale heritage sites and their surrounding paleoenvironment, and high-resolution data are critical for specific local-scale ruins.

The geometry of SAR imaging (i.e., incidence angle together with satellite flight path) has close relationship to surface backscattering. Compared with incidence angle, the impact of satellite flight path (ascending and descending acquisitions) is more significant in archaeological applications because of the interactions between the sensitivity of radar echoes and linear features on the earth's surface. Strong linear backscattering anomalies on SAR images can be observed when the flight path is approximately parallel with linear archaeological features.

Images from multimode (e.g., multifrequency, multitemporal, and multi-polarization) SAR platforms provide different sensed parameters, which are beneficial for the detection of archaeological remains. However, the heterogeneity of data brings in the complexity of image processing and interpretation. For instance, the scattering mechanism that determines the relationship between radar waves and surface/subsurface echoes needs to be investigated for the SAR data optimization. Moreover, the normalization of multimode SAR data is also essential for the performance comparison and assessment.

Apart from the local-scale archaeological signs (crop, soil, and shadow), ancient ruins alter regional landscape that could be observed by remote sensing images and derived added-value products, resulting in the rise of a new subdiscipline of landscape archaeology. Landscape analysis became an irreplaceable component in SAR remote sensing for archaeology. Considering the relationship between the occurrence of ancient ruins and topography, such as those located in high-level wetland platforms, SAR interferometry (InSAR)-derived DEM can be used for identifying potential site.

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