ARCHAEOLOGICAL MAPPING THROUGH OPTICAL AND SAR IMAGERY IN THE HINTERLANDS OF OSTIA AND PORTUS (ITALY)

Michele Abballe[1], Francesca Cigna[1], Deodato Tapete[2]*

1. National Research Council (CNR), Institute of Atmospheric Sciences and Climate (ISAC)

2. Italian Space Agency (ASI)

* m.abballe@isac.cnr.it

Consiglio Nazionale delle Ricerche

ISAC

Agenzia Spaziale Italiana

ABSTRACT

SAR data have been exploited for archaeological studies since the 1980s, but mainly in arid environments. To assess the effectiveness of SAR-based archaeological prospection in temperate environments, we choose the Tiber river mouth as an ideal case study for the presence of a rich cultural landscape gravitating around the abandoned Roman towns of Ostia and Portus. After a preliminary mapping through optical images and existing archaeological data, we proved that multitemporal averaging of SAR amplitude components can be exploited to map crop marks related to different archaeological features.

INTRODUCTION

SAR data have been exploited for archaeological studies since the 1980s, but this powerful tool can still be considered a niche application in archaeological research, due to a technical skill-gap across the archaeological community [1] and the current exploitation of these data mostly limited to arid environments in the Middle East, Northern Africa, and South America [2].

So far, few applications in other environmental contexts have been attempted, such as in temperate environments in Western [3] and Southern Europe [4]. However, the results achieved were not considered satisfactory in terms of archaeological mapping [5].

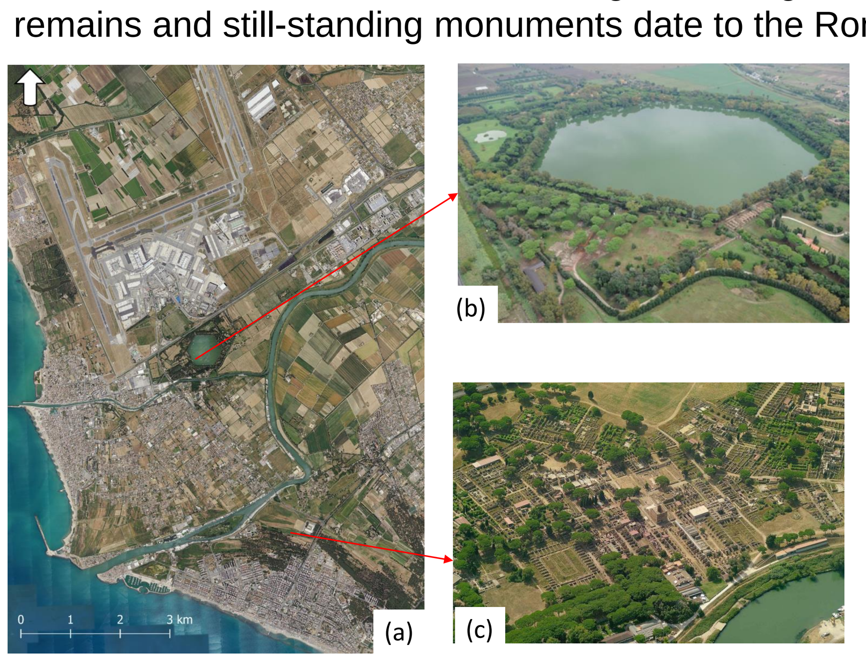
OBJECTIVES

- To assess the effectiveness of SAR-based archaeological prospection in temperate environments, using the Tiber mouth cultural landscape in central Italy as a case study
- To improve the understanding of settlement patterns and the environmental evolution of the study area through a multi-source satellite data mapping

STUDY AREA

Ostia and Portus are two abandoned Roman towns located near the Tiber river mouth (Fig. 1a), around 23 km southwest of Rome (Italy). Both port sites (Figg. 1b and 1c) were created for purely commercial purposes, soon becoming cities of considerable size and wealth.

The hinterlands of these two cities constitute an important cultural landscape with natural traces related to both the Tiber river and the Tyrrhenian coast, and archaeological features dating from the 3rd millennium BCE to the Modern Age, although most archaeological remains and still-standing monuments date to the Roman period.



Artificial hexagonal harbour basin of **Portus**, built in the 2nd century CE

Abandoned town of **Ostia**, occupied since the 4th century BCE and progressively abandoned by the 9th century CE

Fig. 1. Case study area (a), with locations of Portus (b) and Ostia (c) archaeological sites.

METHODS

GIS archaeological mapping

Collecting existing data

Satellite commercial optical basemaps (Google Earth, Esri, Bing)

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National aerial orthophotos

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Archaeological literature review (surveys, remote sensing, geophysics, excavations)

SAR processing, validation and interpretation

22 COSMO-SkyMed images captured in August 2021 by 4 X-band satellites: f = 9.6 GHz, λ = 3.1 cm

Enhanced Spotlight Mode (1m resolution, 10 km swath) with 5 acquisition beams (ES-0B: θ = 22.56°, ES-07: θ = 32.96°, ES-14: θ = 41.35°, ES-27: θ = 54.22°, ES-35: θ = 59.19°)

VV polarization, geocoded with 2m national LiDAR DSM

↓

Processing of amplitude component = change detection, multitemporal averaging, spatial filtering

↓

Validation through multispectral images:

- 8 Sentinel-2 MSI Level-2A products at 10m resolution (G, R, B, NIR bands)
- 22 PlanetScope images with surface reflectance, 4 bands (G, R, B, Nir), 3m resolution, NO UDM2

↓

Archaeological mapping in SAR products

RESULTS

Preliminary archaeological mapping

The interpretation of optical satellite and aerial images allowed us to map 1199 natural and anthropogenic features in the hinterlands of Ostia and Portus:

- several structures including funerary (51) and commercial/residential buildings (320)
- extensive infrastructures such as canals (328), streets (75), city walls and aqueducts (25)
- hundreds of km of natural features, such as beach ridges (89), paleochannels and scrollbars (267)

All these features will be used as reference to interpret SAR products.

Change detection to identify crop status changes

Ratio (Fig. 2c) between end (Fig. 2b = 31/08/2021) and start (Fig. 2a = 07/08/2021) of campaign amplitude values indicates:

- a backscatter decrease in the blue and green fields
- a backscatter increase in the red field

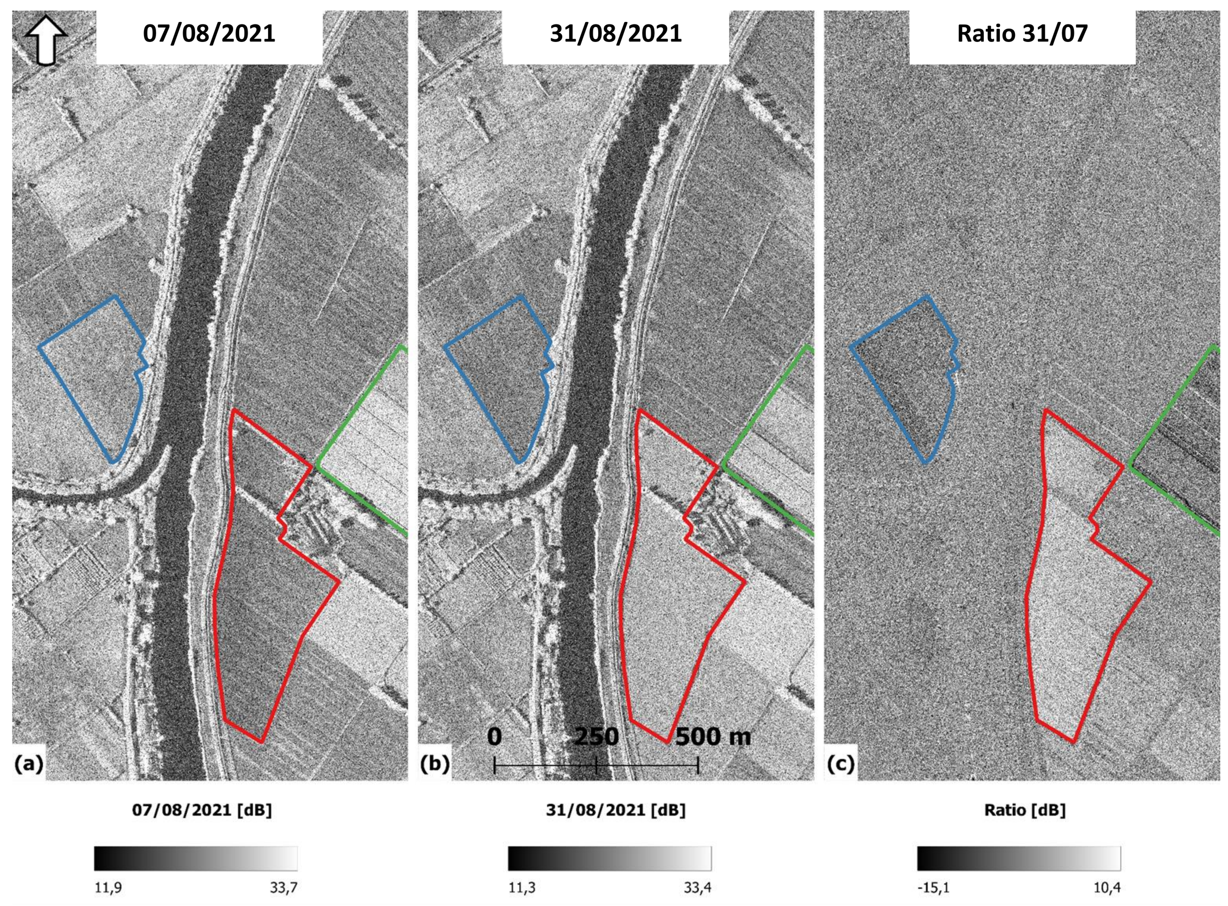


Fig 2. SAR amplitude results from 7th (a) and 31st of August 2021 (b), and b/a ratio (c).

Change detection interpretation

Sentinel-2 and PlanetScope data (Fig. 3) suggest a vegetation reduction on the 16th-18th of August 2021 that explains the backscatter decrease in the blue field in Fig. 2. Spectral analysis with decreasing NDVI values (Graph 1) indicates reduction of the vegetation cover.

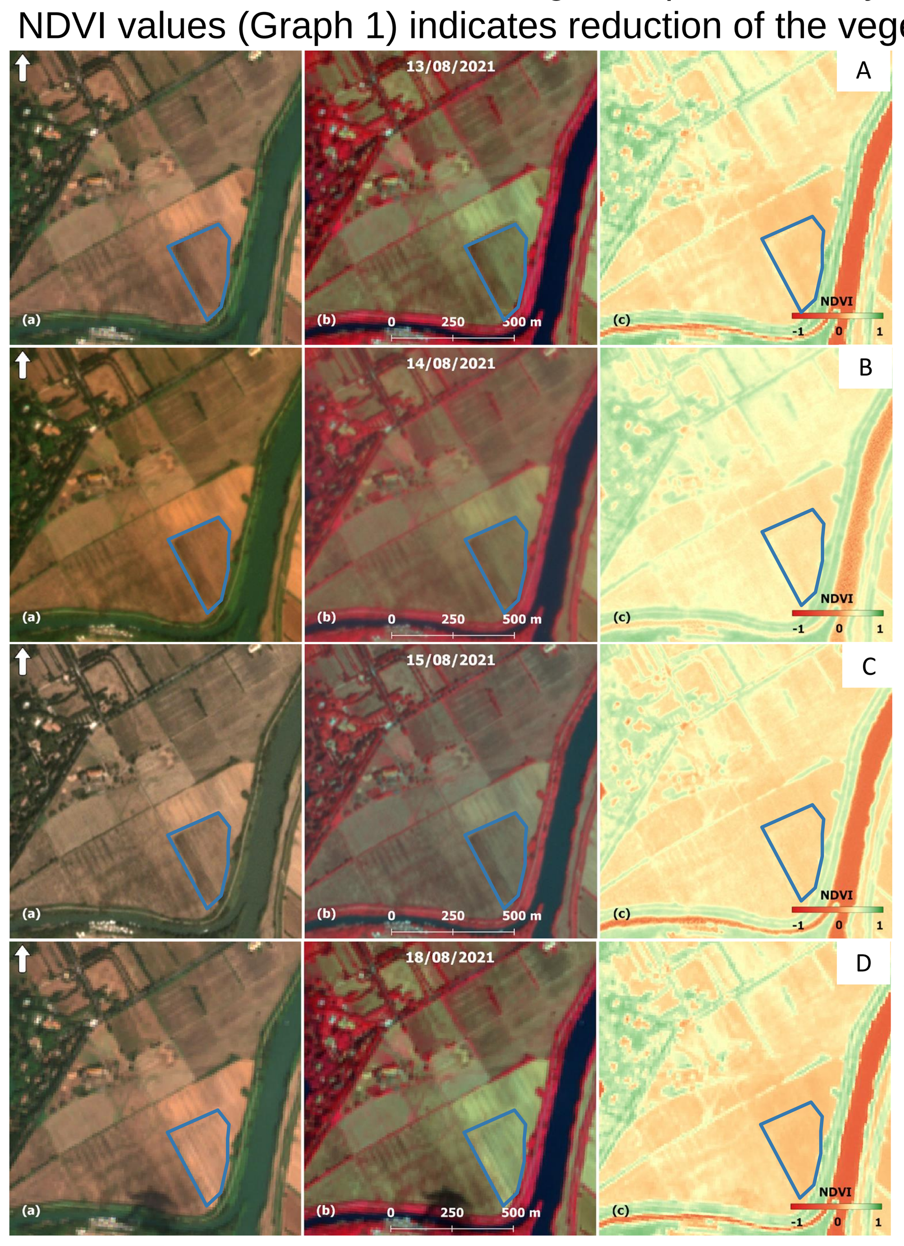
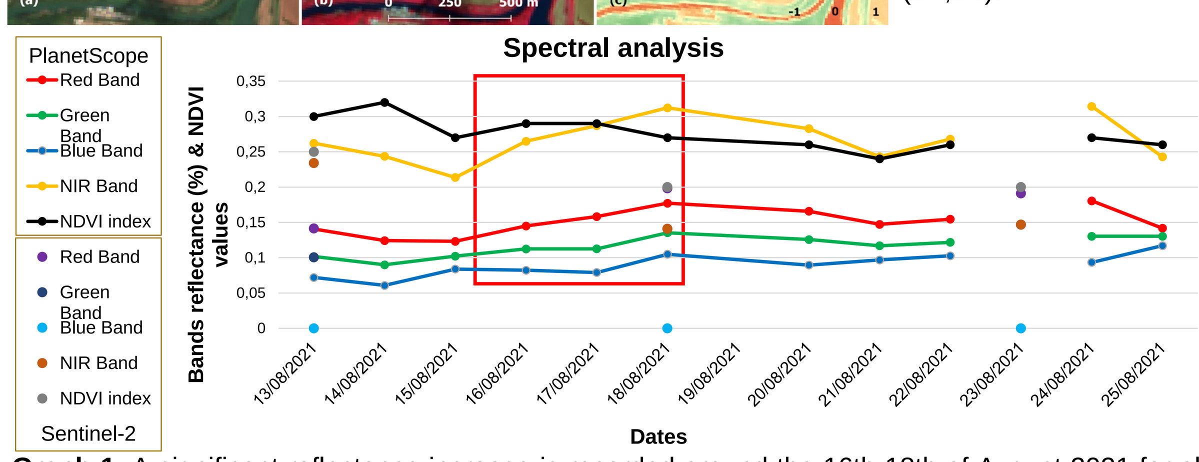


Fig. 3. Validation of land cover changes through Sentinel-2 (A, D):
(a) = True colour (R=B4, G=B3, B=B2)
(b) = False colour (R=B8, G=B4, B=B3)
(c) = NDVI := Index (B8,B4);
and PlanetScope images (B, C):
(a) = True colour (R=B3, G=B2, B=B1)
(b) = False colour (R=B4, G=B3, B=B2)
(c) = NDVI := Index (B4,B3).



Graph 1. A significant reflectance increase is recorded around the 16th-18th of August 2021 for all bands, with a contemporary NDVI decrease that suggests reduction of vegetation canopy.

Multitemporal averaging

Averaging of several SAR images acquired with the same acquisition parameters significantly reduces noise and successfully highlights persistent features of archaeological interest (Fig. 4).

The red polyline highlights the site of a rectangular Roman mausoleum located within the blue field of Figg. 2-3, which is:

- not visible in a single image (a)
- visible in an average of 4 images before the land-cover change (b)
- not visible in an average of 3 images after the land-cover change (c)
- visible in an average of 7 images spanning the month of August (d)

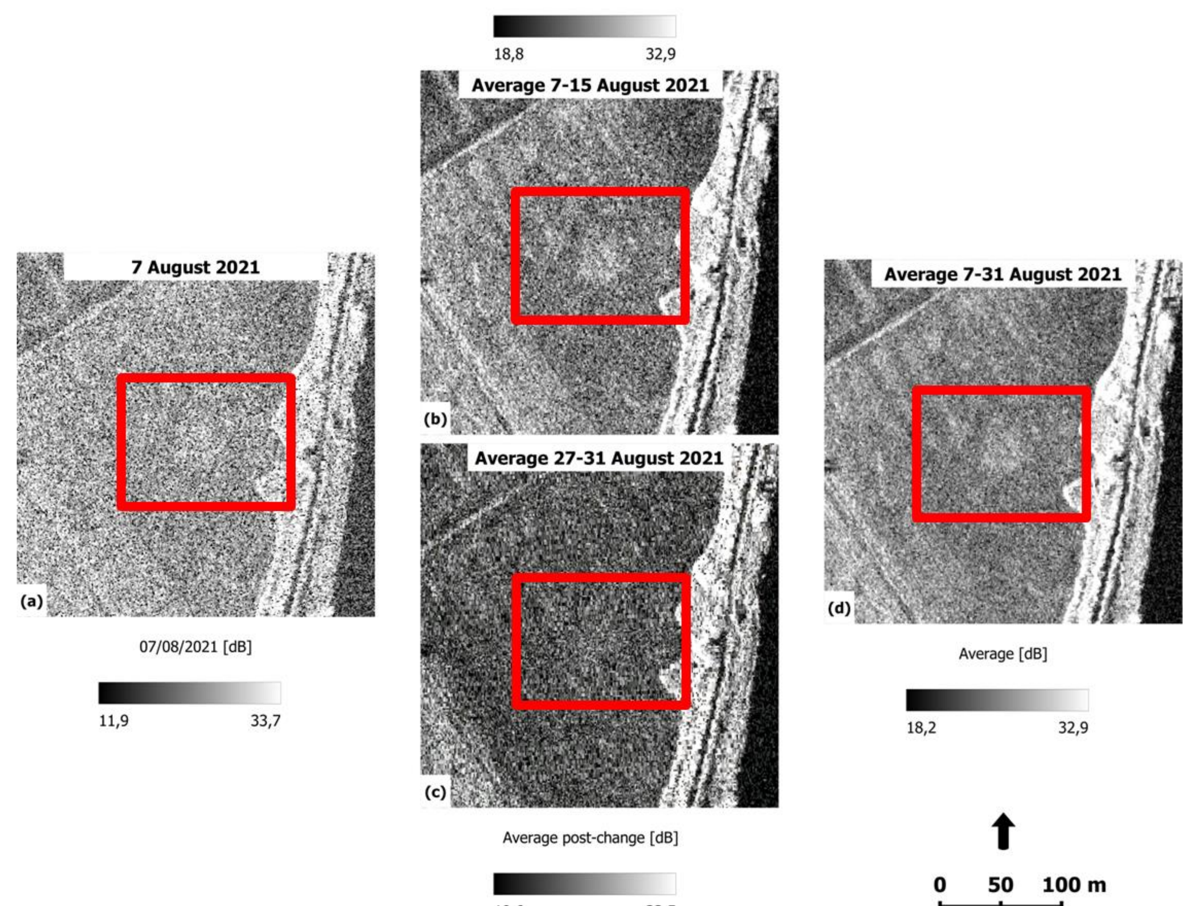


Fig. 4. Single SAR image from 7th of August 2021 (a), averaging of 4 SAR images between the 7th and 15th of August 2021 (b), averaging of 3 SAR images between 27th and 31st of August 2021 (c), averaging of 7 SAR images between the 7th and 31st of August 2021 (d). The red polyline indicates a rectangular feature interpretable as a Roman mausoleum.

Spatial filters testing for archaeological mapping

The widely-used Lee Sigma filter applied to Fig. 4d averaged product further reduces speckle (Fig. 5), but with no significant contribution in terms of archaeological readability.

Large window size (=11 m) and setting values (Sigma≥5, M-threshold≥2) worsen the readability of the original product (Fig. 5a-b).

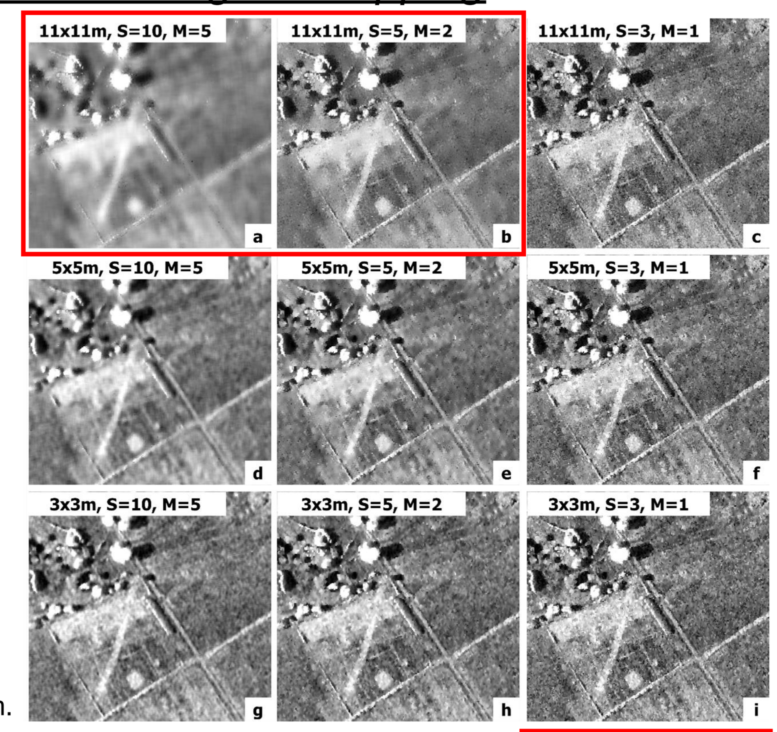


Fig. 5. Testing of Lee Sigma filter: the red polygon indicates products not suitable for archaeological interpretation.

The Adaptive filter (Fig. 6) can also further reduce speckle, but with no significant contribution in terms of archaeological readability.

Large window values (≥5 m) with small standard deviation setting (=1) actually worsen the readability of the original product (Fig. 6c-f).

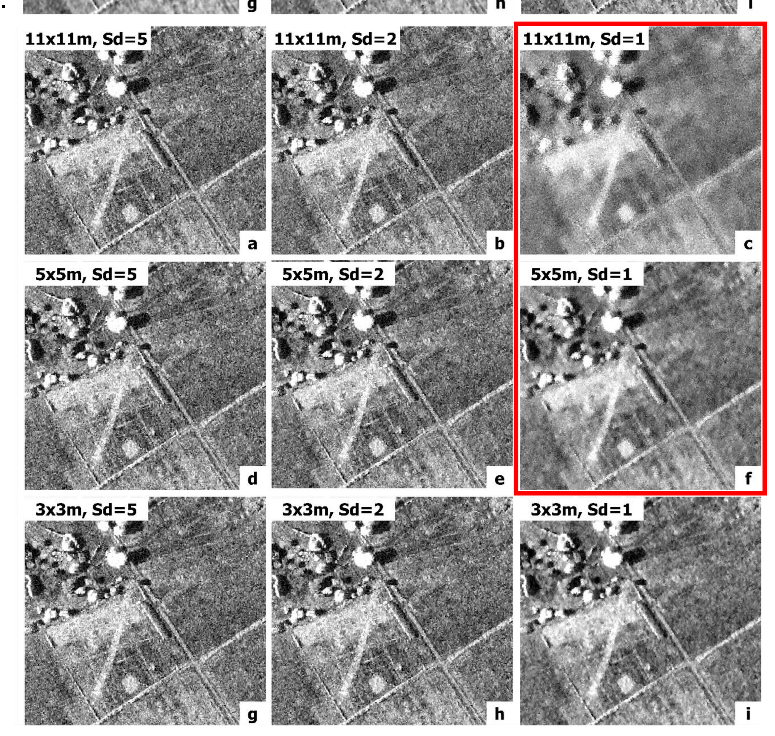


Fig. 6. Testing of Adaptive filter: the red polygon indicates products not suitable for archaeological interpretation.

DISCUSSION

The averaged product of 7 SAR images captured between the 7th and 31st of August 2021 with ES-35 acquisition beam (θ = 59.19°) proved to be most effective in highlighting crop marks related to archaeological features. A total of 76 unique features were mapped, mostly clustering in the areas of the Northern Canal (Fig. 7), Capo due Rami (Fig. 8) and Pianabella (Fig. 9), of which 18 new ones that were not present in the reference collection.

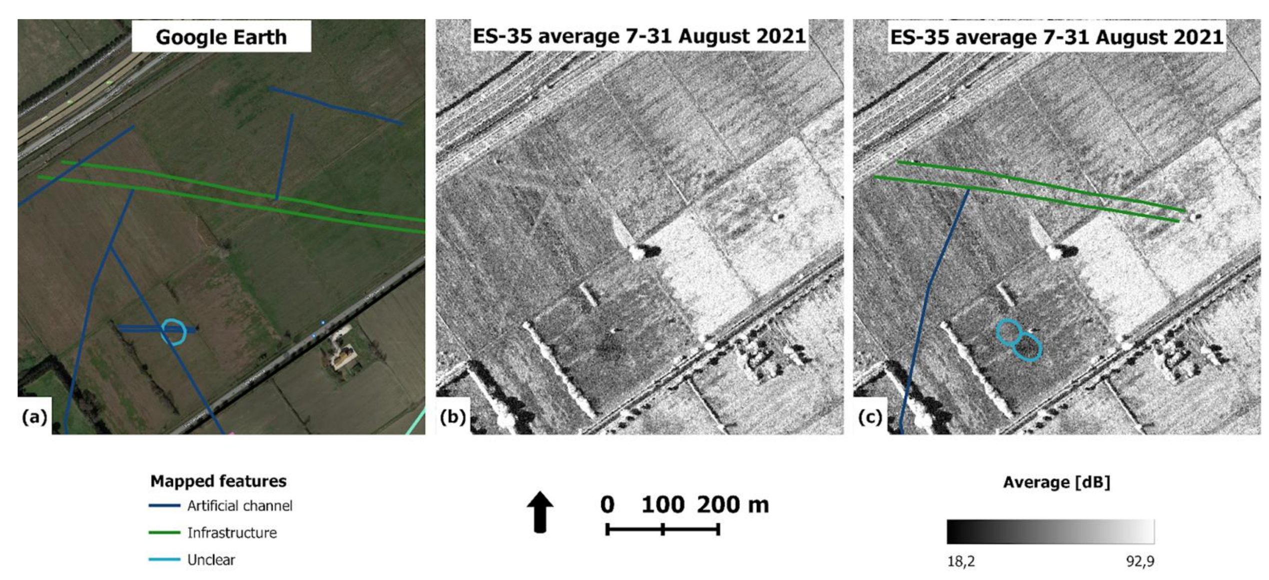


Fig. 7. Northern Canal area, northeast of Portus hexagonal basin: preliminary archaeological mapping (a), averaged SAR product (b) with archaeological interpretation (c).

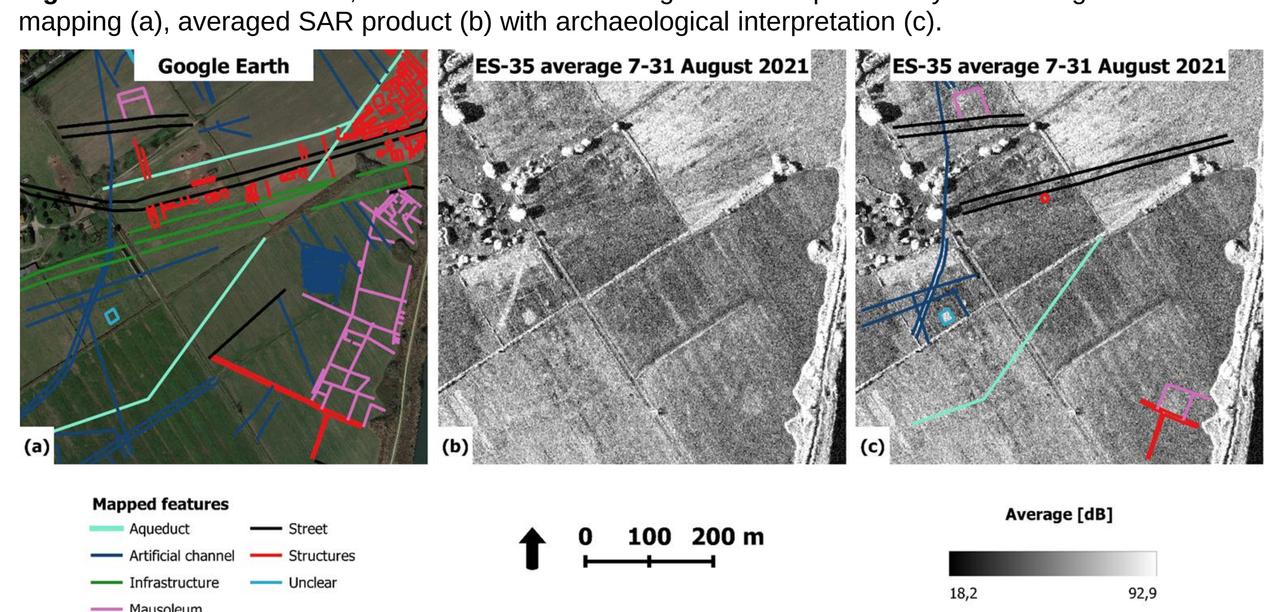


Fig. 8. Capo due Rami area, southeast of Portus hexagonal basin: preliminary archaeological mapping (a), averaged SAR product (b) with archaeological interpretation (c).

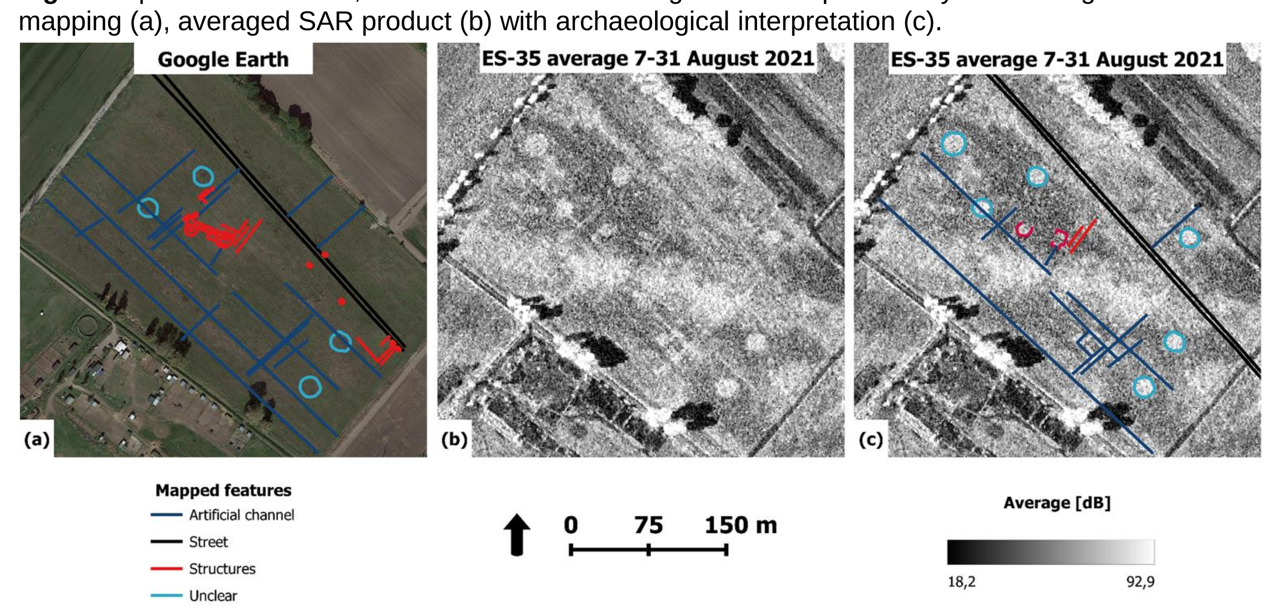


Fig. 9. Pianabella area southeast of Ostia: preliminary archaeological mapping (a), averaged SAR product (b) with archaeological interpretation (c).

CONCLUSIONS AND FUTURE WORK

- SAR images successfully identified crop marks related to different features of archaeological value that we can interpret as streets, channels and a variety of structures thanks to our preliminary mapping
- Spatial filters do not improve significantly the archaeological interpretation
- Sudden vegetation changes often do not lead to the disappearance of (archaeological) features if they persisted in several images
- New acquisition campaign in 2022 by COSMO-SkyMed (1m) and SkySat (0.5m) satellites, supported by ASI data grant Multi-SAR, ESA Cat-1/EO Data User Project GEOARCHAMMI, and on-site verifications.

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