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Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL

Gateway to the Earth

Addressing global challenges in conservation and digital recording of UNESCO sites with VHR radar space technology

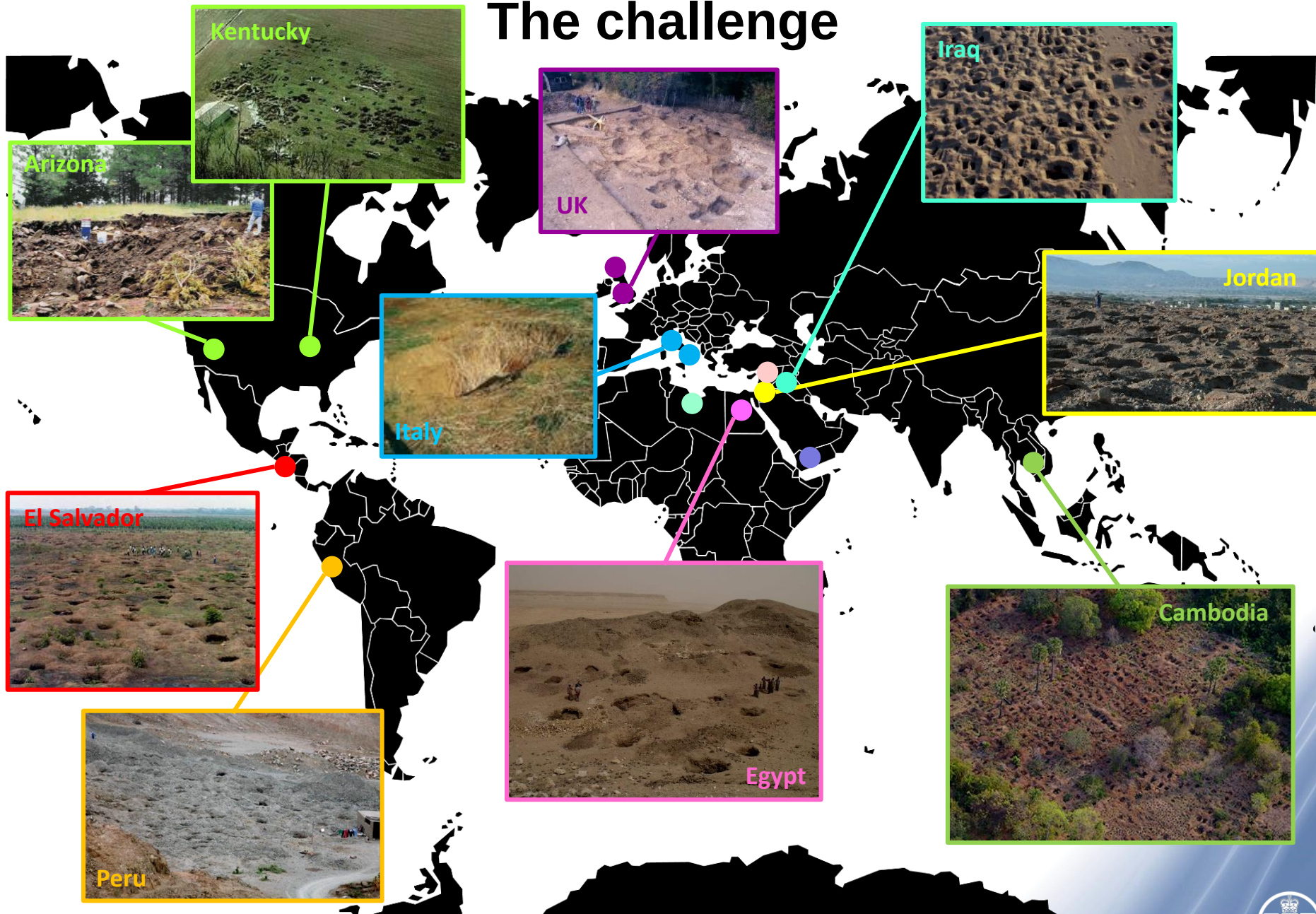
D. Tapete & F. Cigna



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The challenge



Middle East & North Africa (MENA)



Heritage Sites Attacked, Targeted, or Destroyed



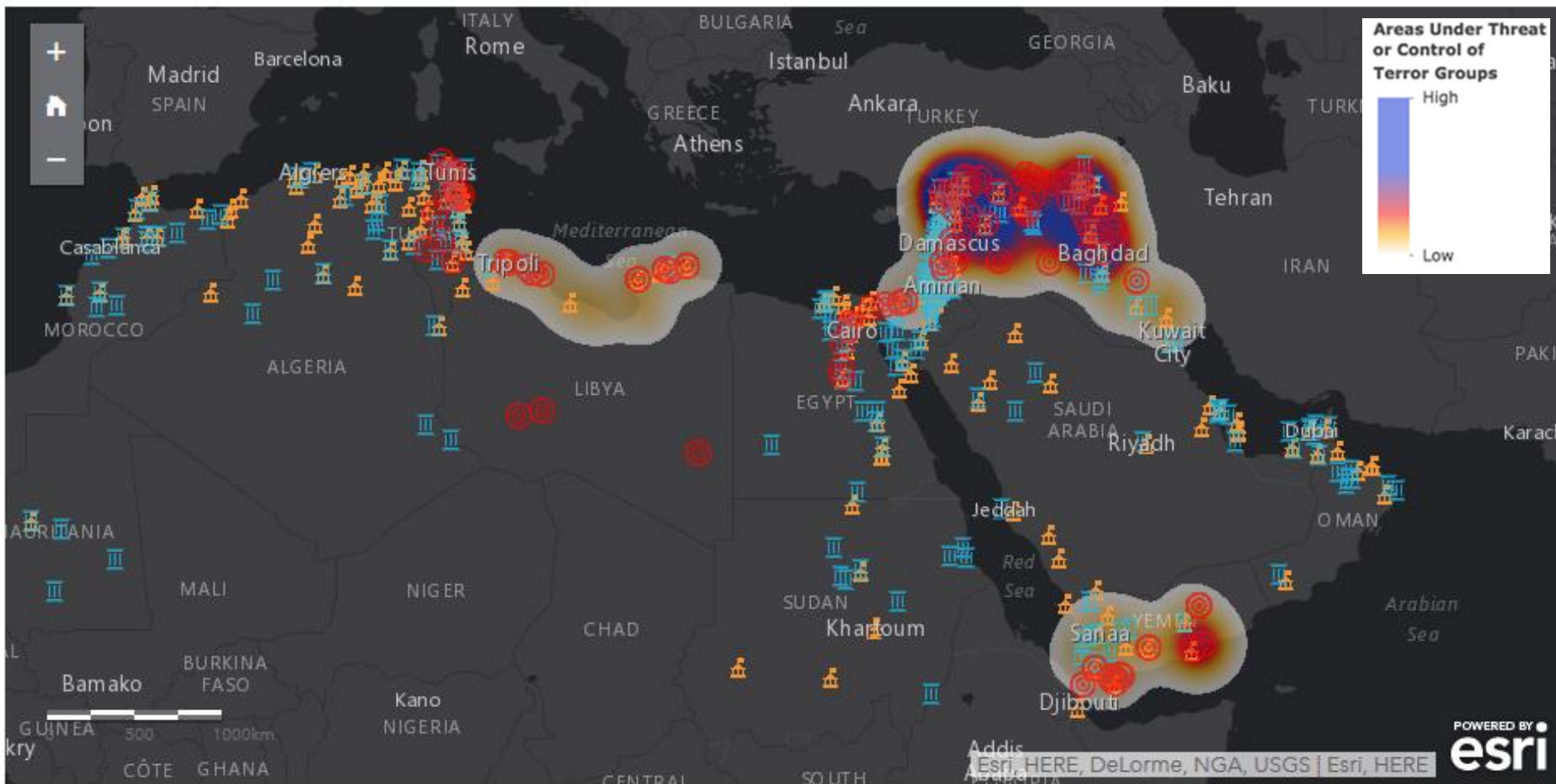
UNESCO World Heritage & Tentative List Sites



Museums

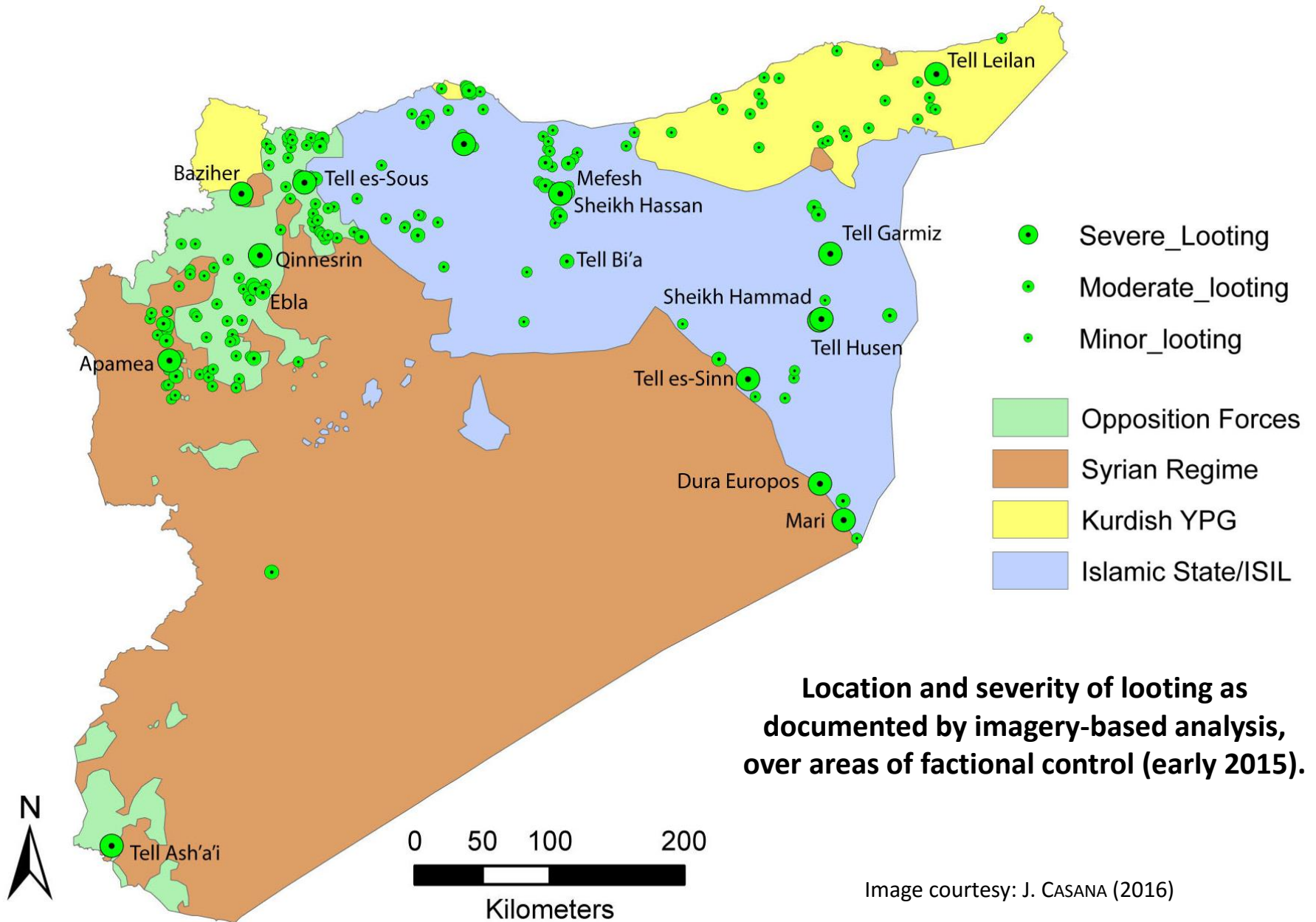


ANTIQUITIES COALITION. 2016. *Culture Under Threat Map*, The Antiquities Coalition.



Culture Under Threat Map

Archaeological looting in Syria



Archaeological looting

Definition:

'Unauthorised excavations without any scientific purpose to rob goods of historical or cultural value to sell on illicit markets'

Crisis and war can favour its spread

Key question:

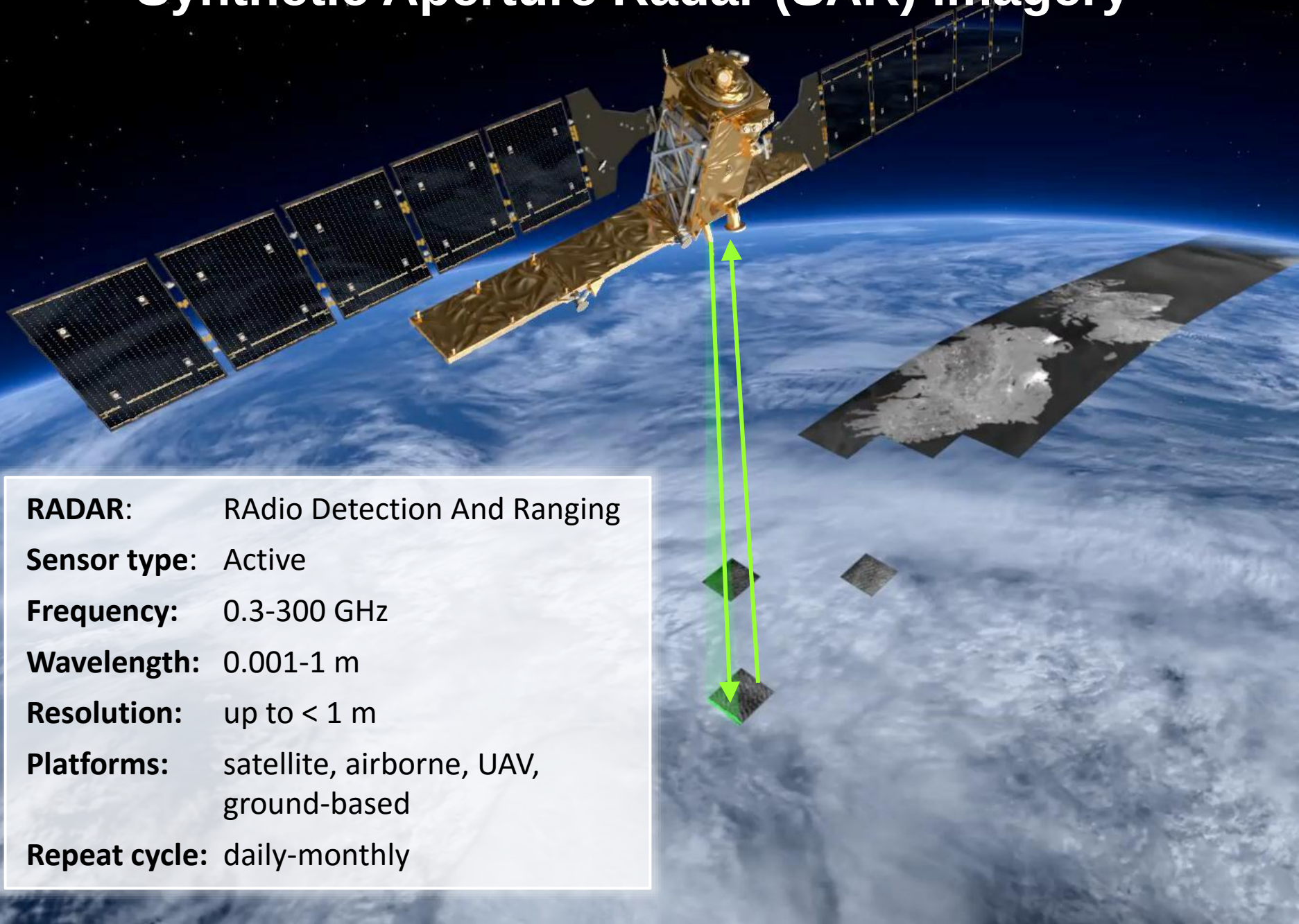
Rate of occurrence?

Satellite data requirements:

1. Very High Resolution (VHR)
2. Regular acquisitions
3. Consistent acquisition geometry
4. Iterative methodology



Synthetic Aperture Radar (SAR) imagery



RADAR: RADio Detection And Ranging

Sensor type: Active

Frequency: 0.3-300 GHz

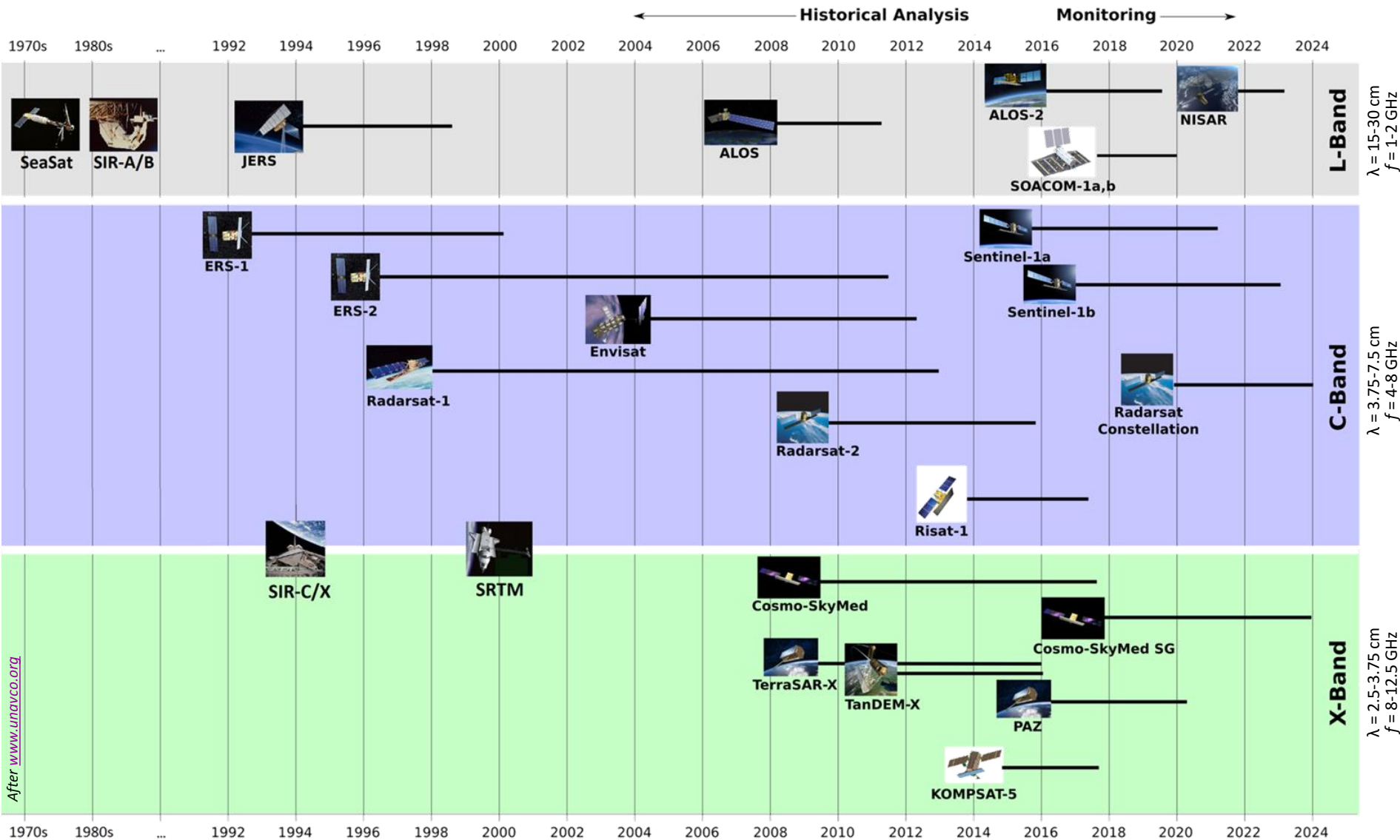
Wavelength: 0.001-1 m

Resolution: up to < 1 m

Platforms: satellite, airborne, UAV,
ground-based

Repeat cycle: daily-monthly

Satellite SAR missions



Acquisition strategies: routine, on demand, emergency

Satellite SAR in archaeology



Jet Propulsion Laboratory
California Institute of Technology



Darfur, Sudan



Landsat MSS



SIR-A data (1981)

Dry rivers revealed
thanks to the radar
penetration capability

Landsat MSS

ELACHI & GRANGER (1982), IEEE Spectrum

Satellite SAR in archaeology

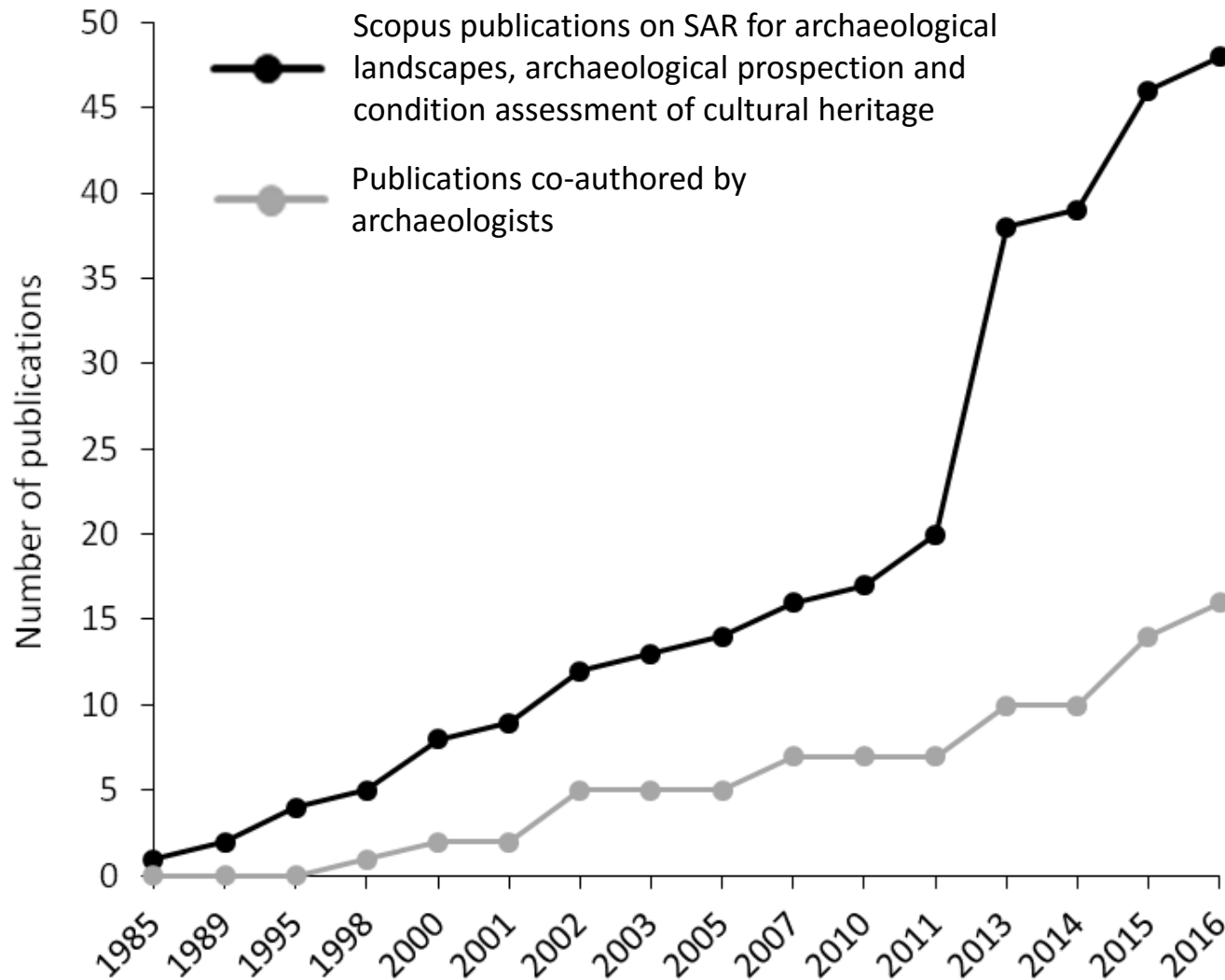
The Open Initiative

Open Initiative on the use of space technologies to support the World Heritage Convention (2003)



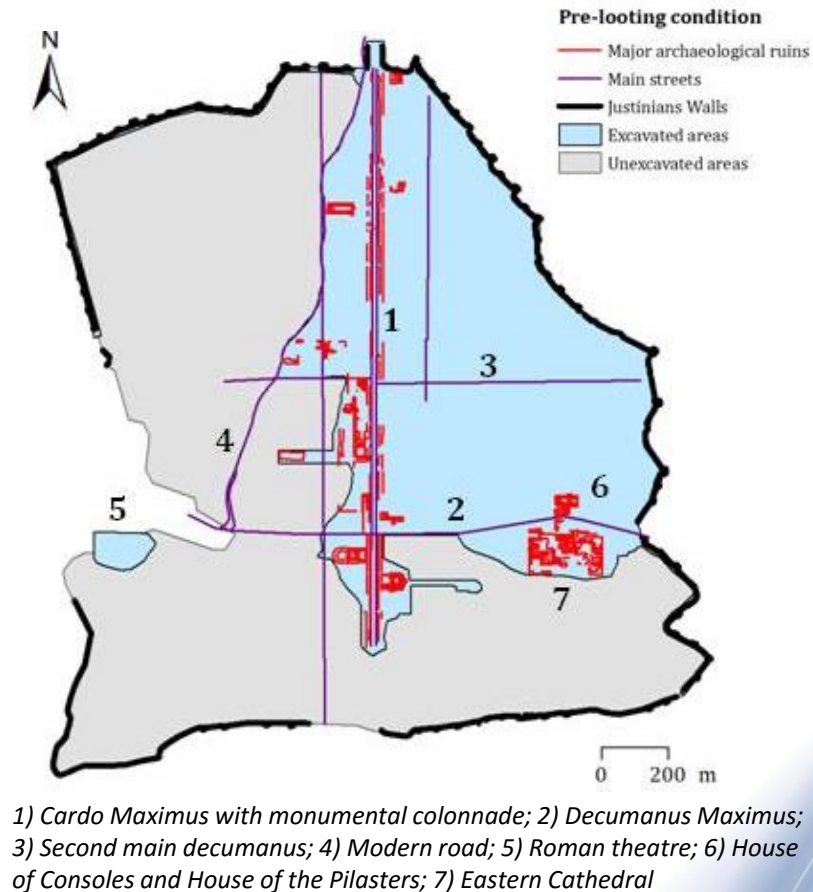
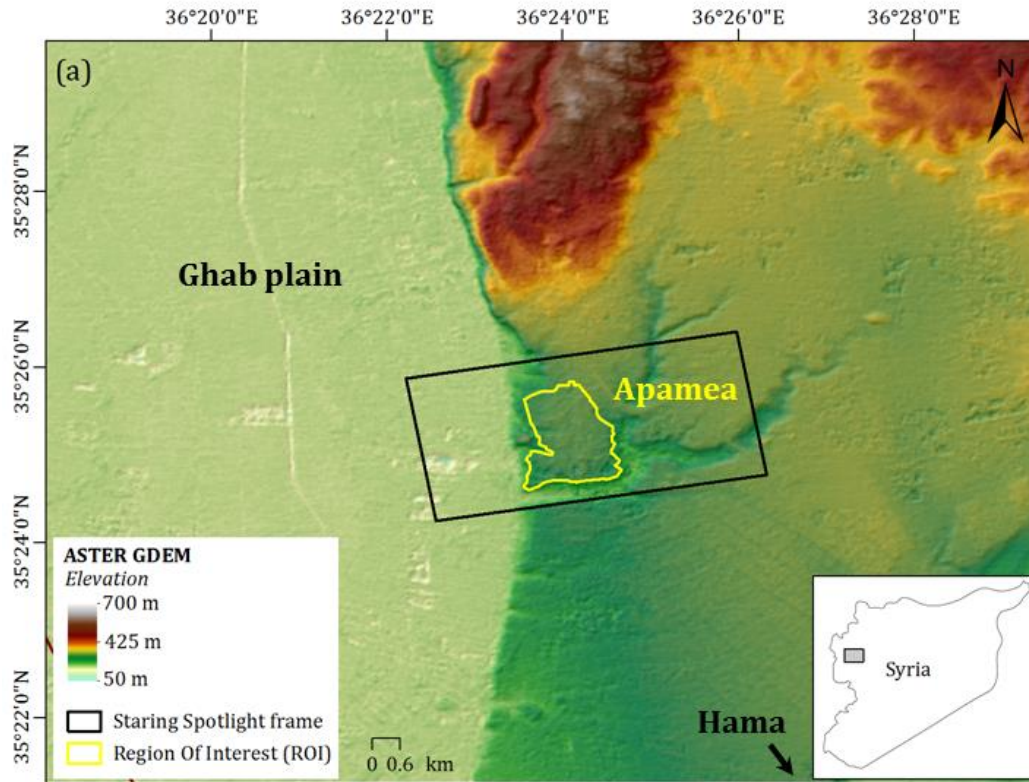
ESA/UNESCO Agreement signature © ESA - M. Pedoussaut 2003

... a growing scientific literature



TAPETE & CIGNA (2016), *J Archaeological Science: Reports*

Archaeological site of Apamea, Syria



- Situated on the right bank of the Orontes, at the top of a high relief overlooking the Ghab plain
- Its strategic position was exploited to control the trade routes by Seleucus Nicator (~300 BC)
- 7 km-long ramparts refortified by the emperor Justinian (~500-600 AD) enclose the site

Cardo Maximus and colonnade at Apamea



Cardo Maximus and colonnade at Apamea



Industrial scale looting

- Evidence of looting starting from mid 2012
- *“Satellite imagery shows that archaeological sites in Syria are dotted by thousands of illegal excavations ... that show there is looting on an **industrial scale**”*

(Irina Bokova, UNESCO, 2015)

- Use of excavators and bulldozers
- Very distinctive planimetric shape
- Holes up to a few metre-wide
- Excavations depths from < 1 m to a few metres (looters' opportunistic rationale)



A look from space

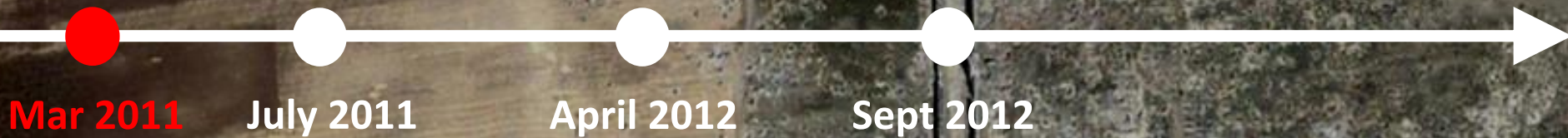
Google earth

A satellite image from Google Earth showing a landscape with a winding road, fields, and some buildings. A timeline is overlaid at the bottom, with a red dot at the left and a white dot further right, both on a white line that ends in an arrow pointing to the right.

Mar 2011 July 2011

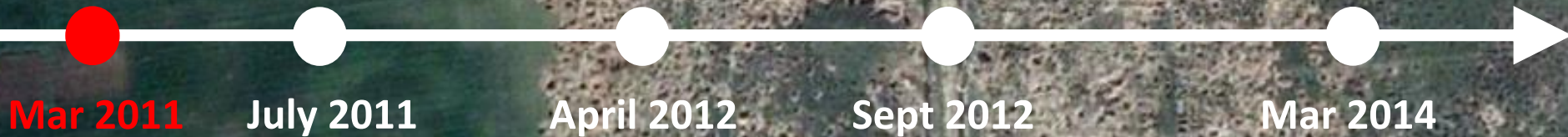
A look from space

Google earth



A look from space

Google earth



Evidence from Google Earth imagery

April 2012

- 0.93 km² (~38%) looted, of which ~75% in excavated sectors, plus ~12% in unexcavated areas

September 2012

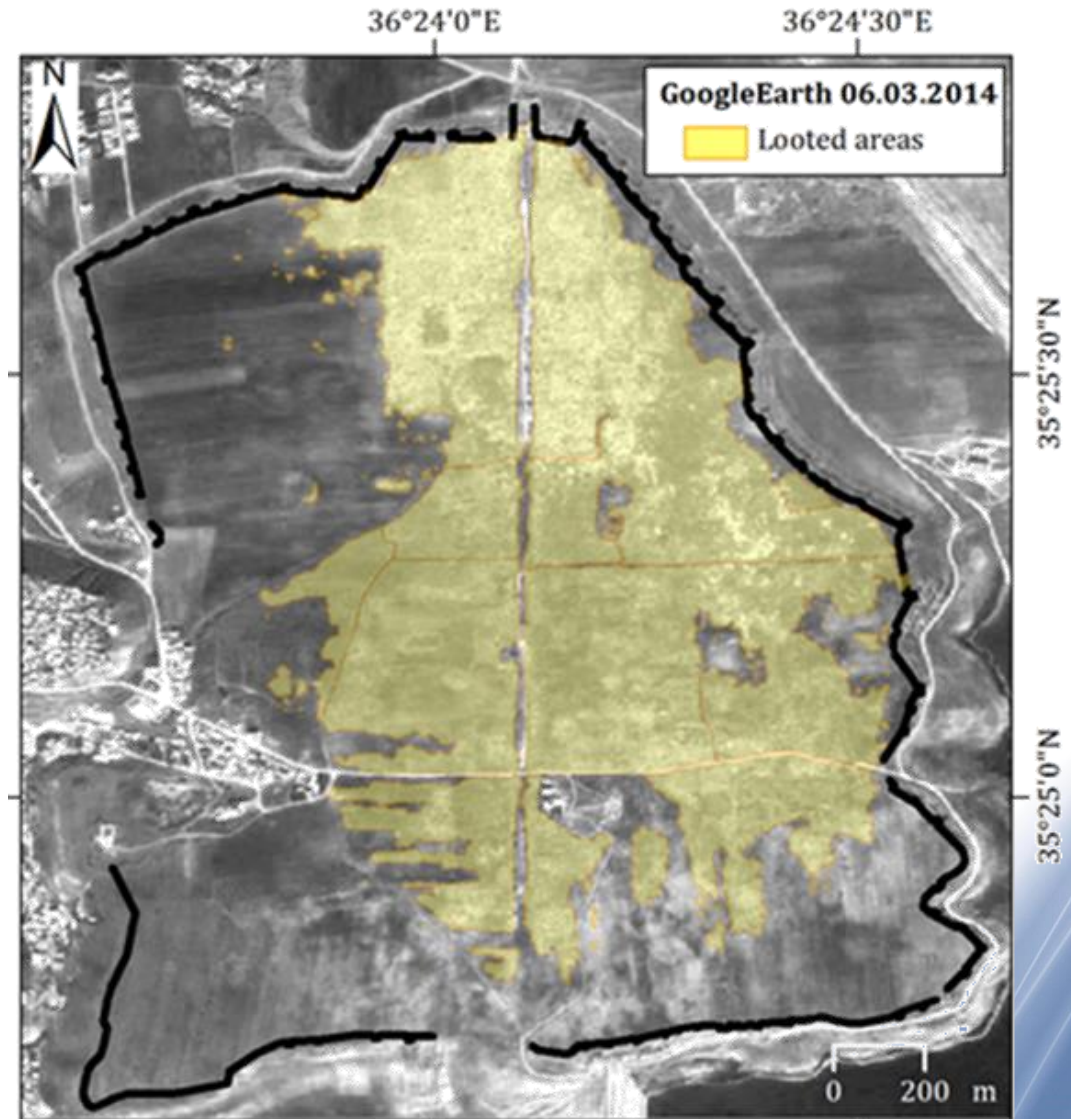
- New looting 0.015 km² NW

March 2014

- Expansion NW up to 0.105 km²

OPEN QUESTIONS

Looting rates?
Repeated looting?



VHR satellite radar experimental campaign



DLR grant LAN2377: *TerraSAR-X Staring Spotlight mode for damage assessment, looting monitoring and prospection of archaeological features in semi-arid environment* (PI: D. Tapete)



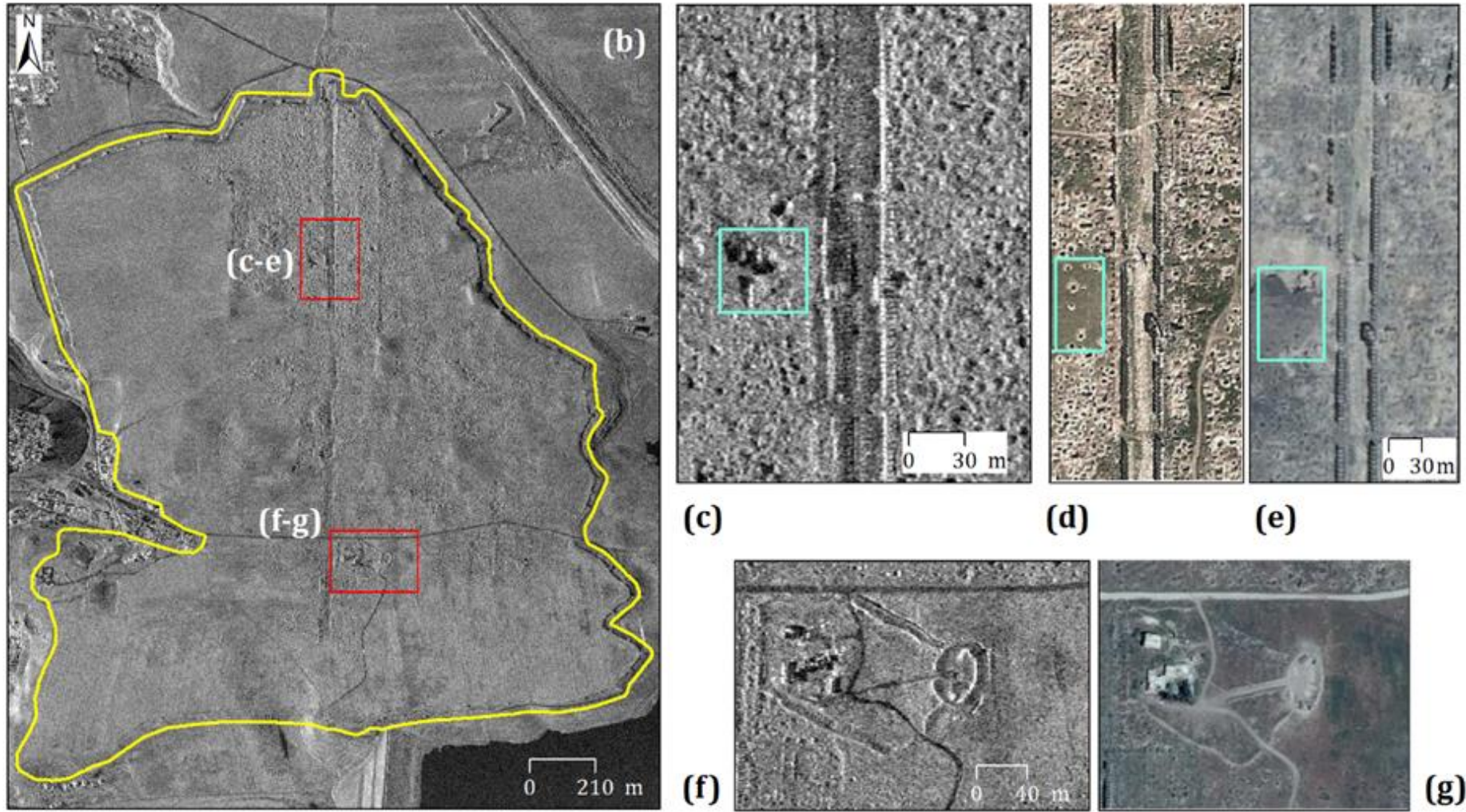
Marie Curie research grant; EU COFUND/Durham Junior Research Fellowship [EU grant agreement no.267209]

October 2014



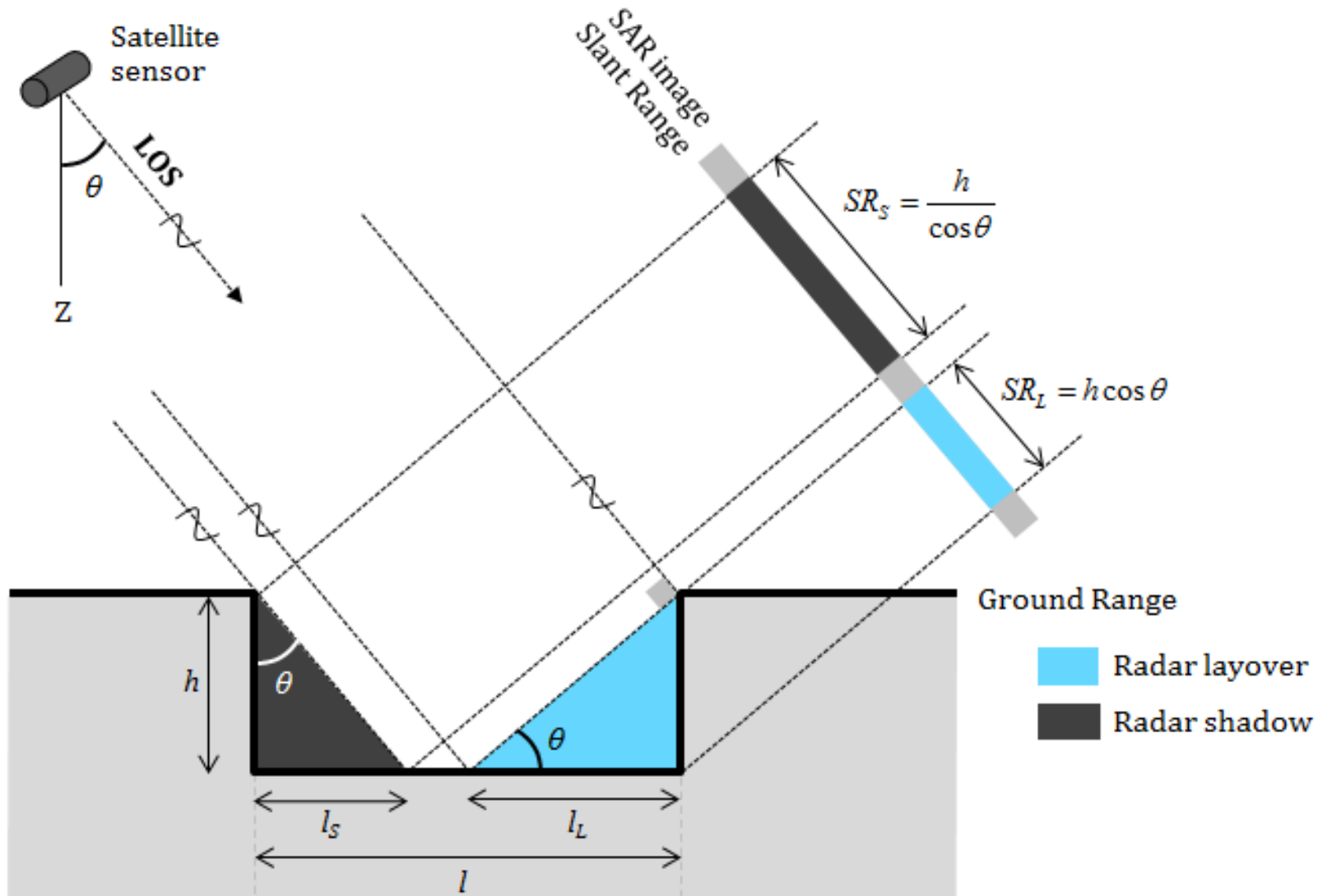
- Bespoke time series of **TSX Staring Spotlight**, bimonthly sampling, **24 cm azimuth resolution**
- Consistent geometry and acquisition parameters: ascending orbits, $39.7^\circ \vartheta$

TerraSAR-X Staring Spotlight imagery



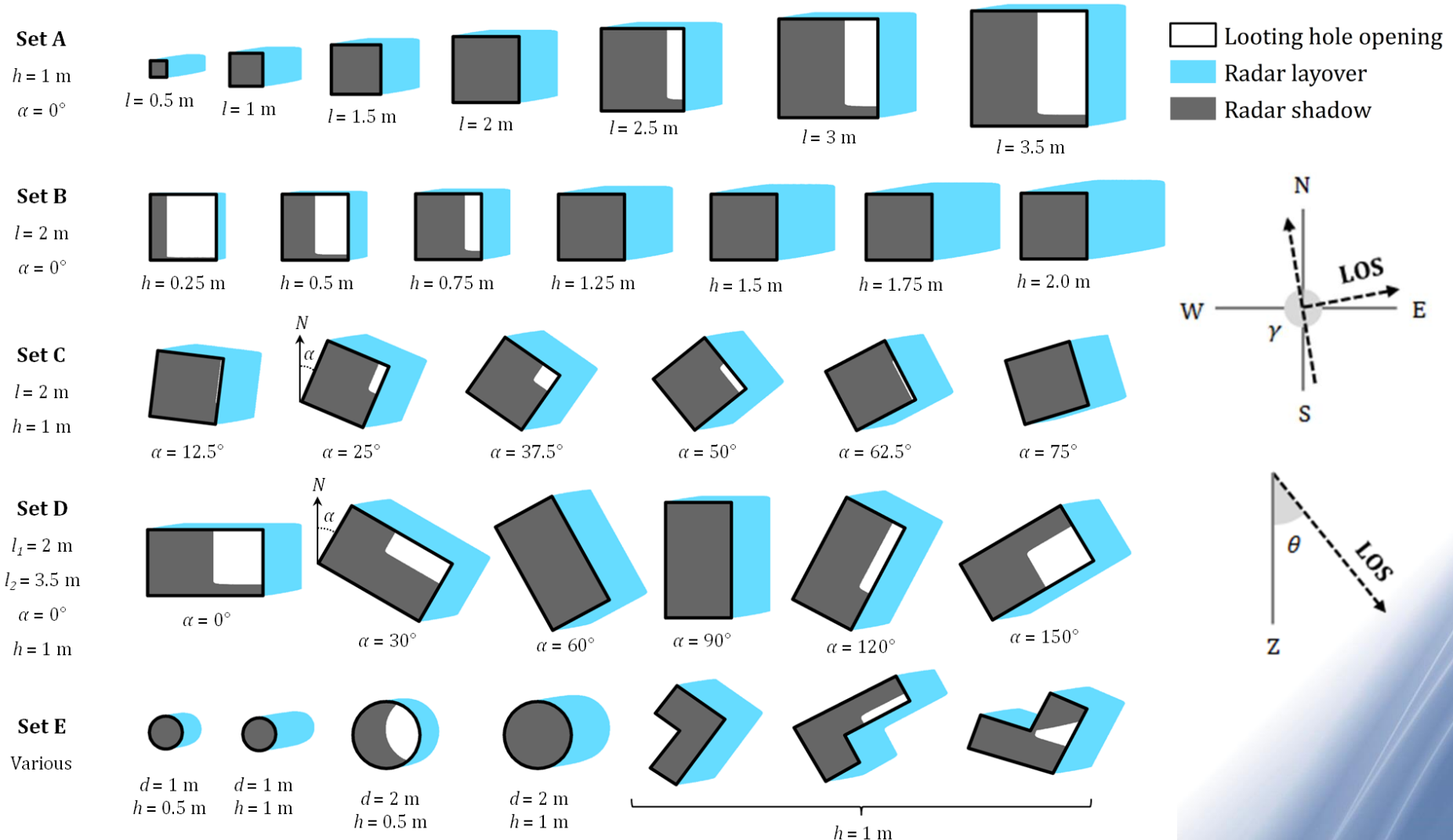
TAPETE *et al.* (2016), Remote Sensing of Environment

Conceptual model



TAPETE *et al.* (2016), Remote Sensing of Environment

Conceptual model

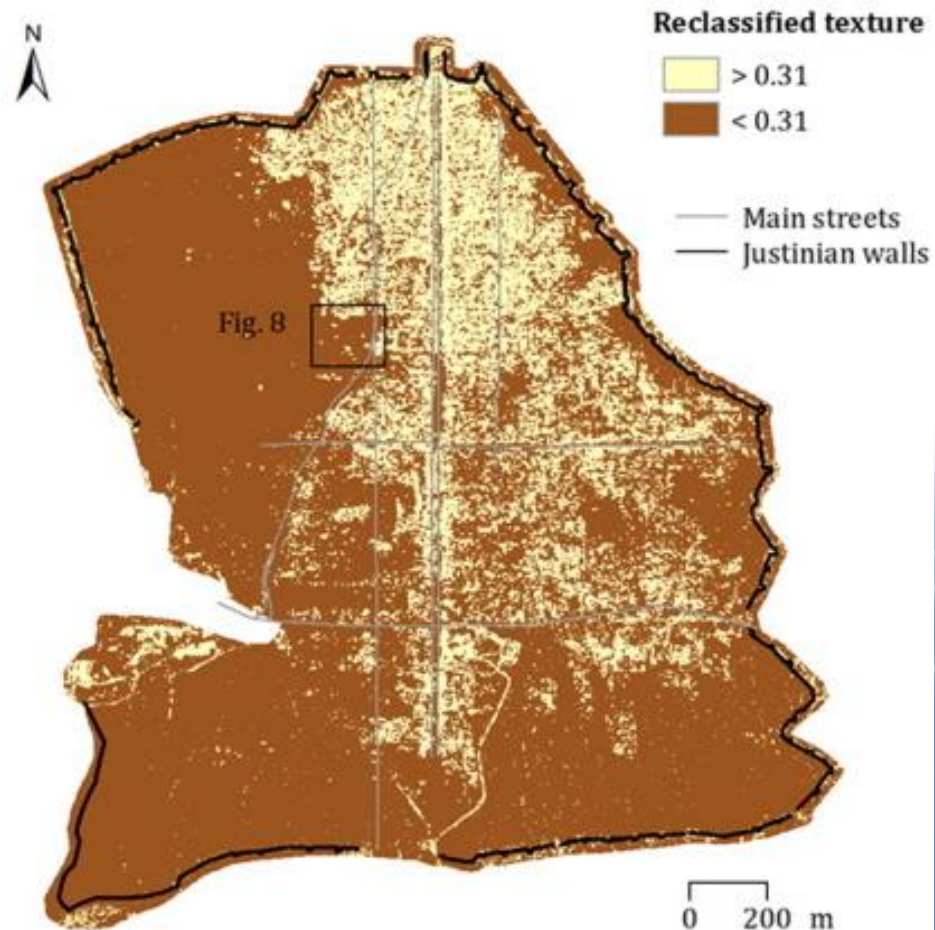
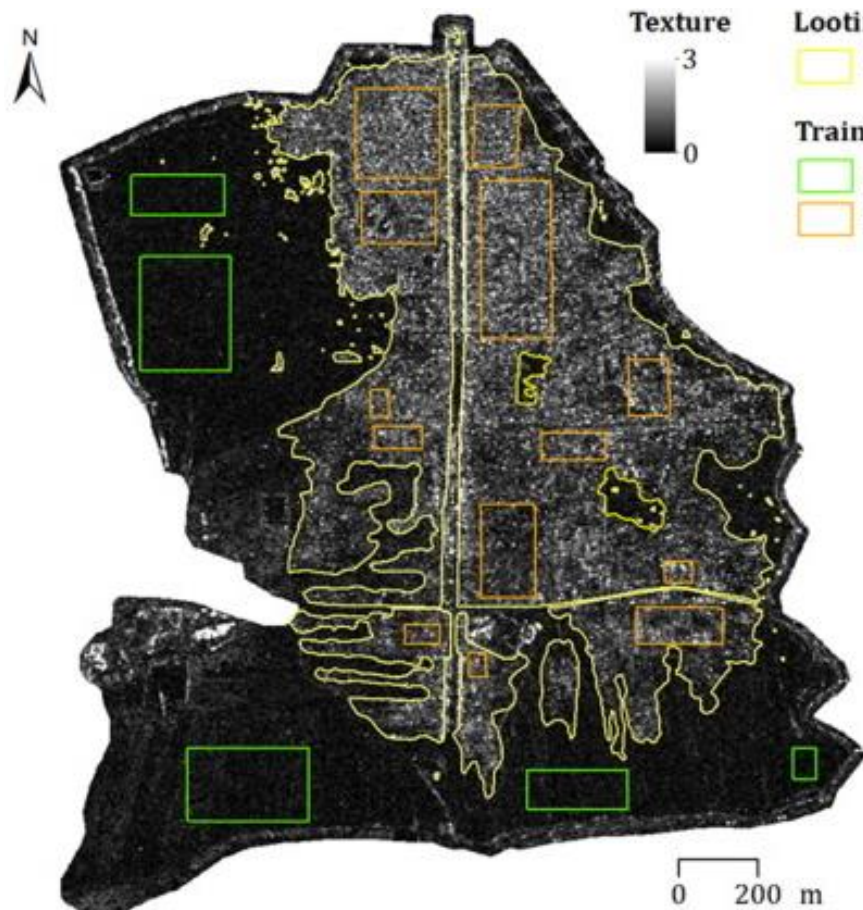


TAPETE *et al.* (2016), Remote Sensing of Environment

Tapete et al. 2016. Remote Sensing of Environment 178, 42-58.
TerraSAR-X Staring Spotlight data © DLR 2015



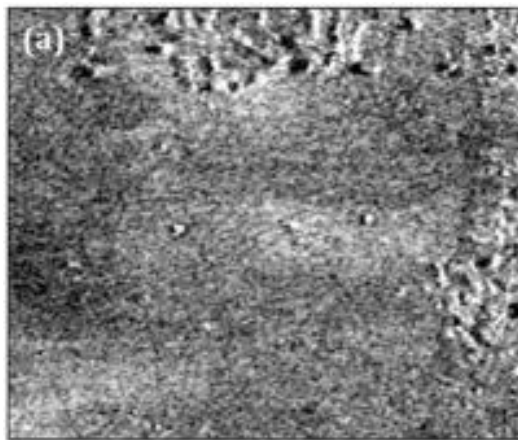
Texture analysis and feature extraction



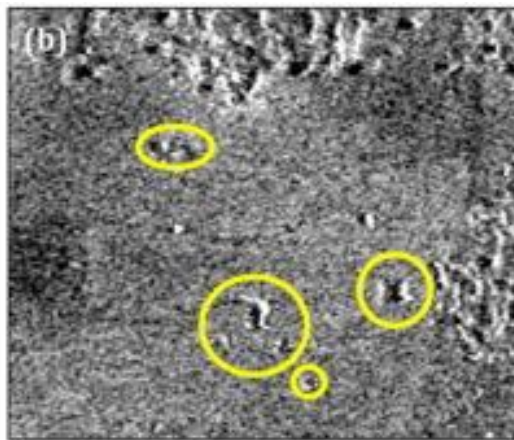
TAPETE *et al.* (2016), Remote Sensing of Environment

Texture analysis and feature extraction

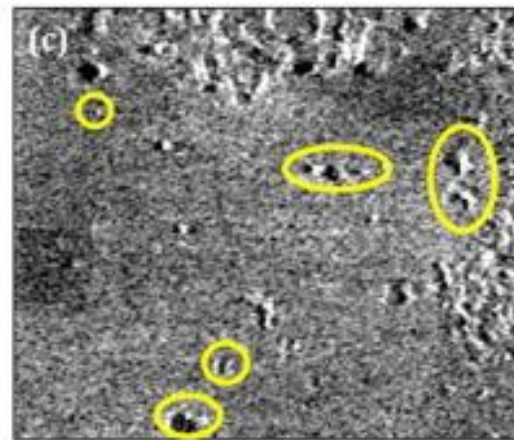
22nd October 2014



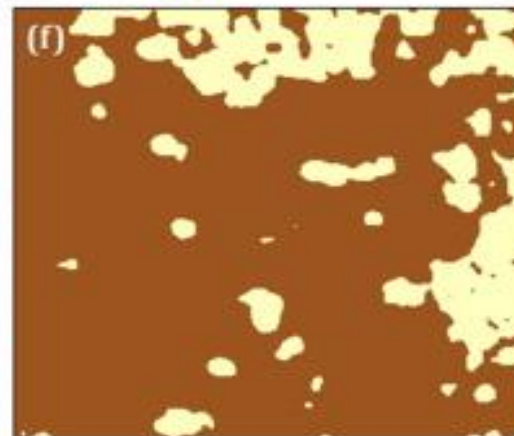
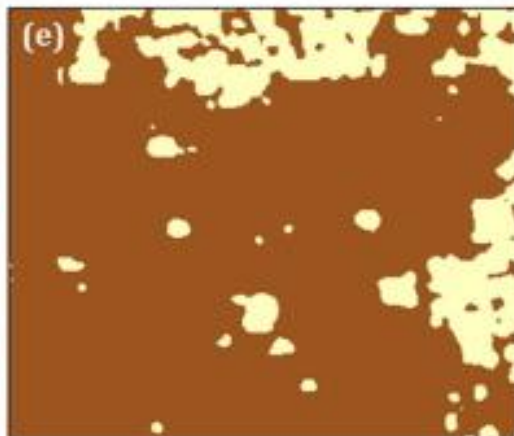
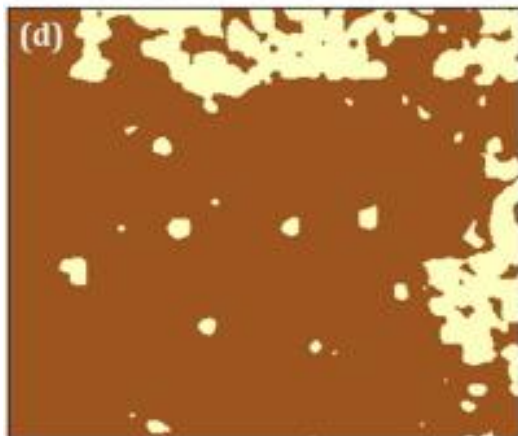
27th December 2014



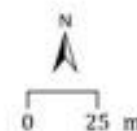
20th February 2015



SAR backscattering
15 dB 90 dB

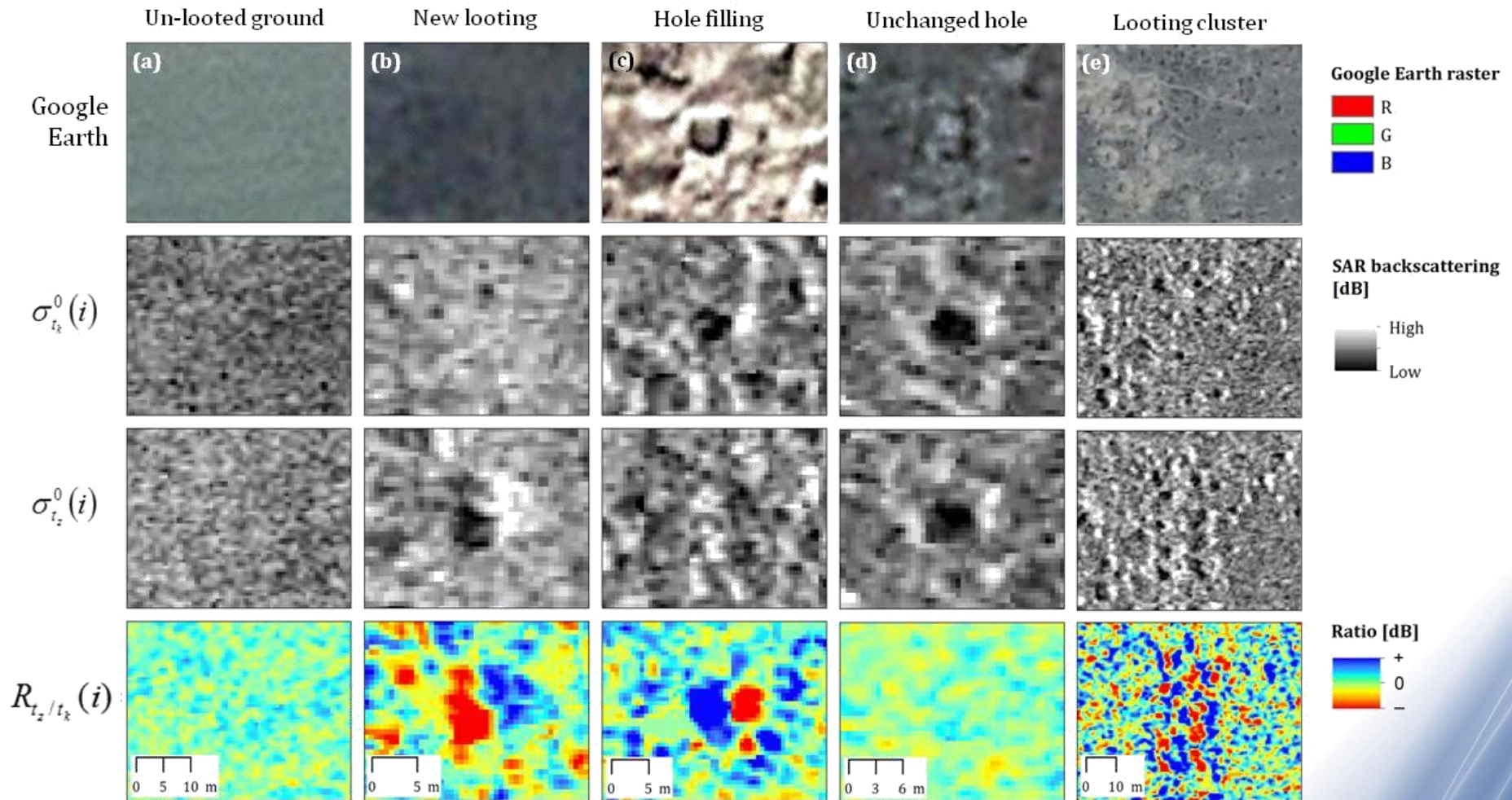


Reclassified texture
Yellow > 0.31 (looted)
Brown < 0.31 (unlooted)



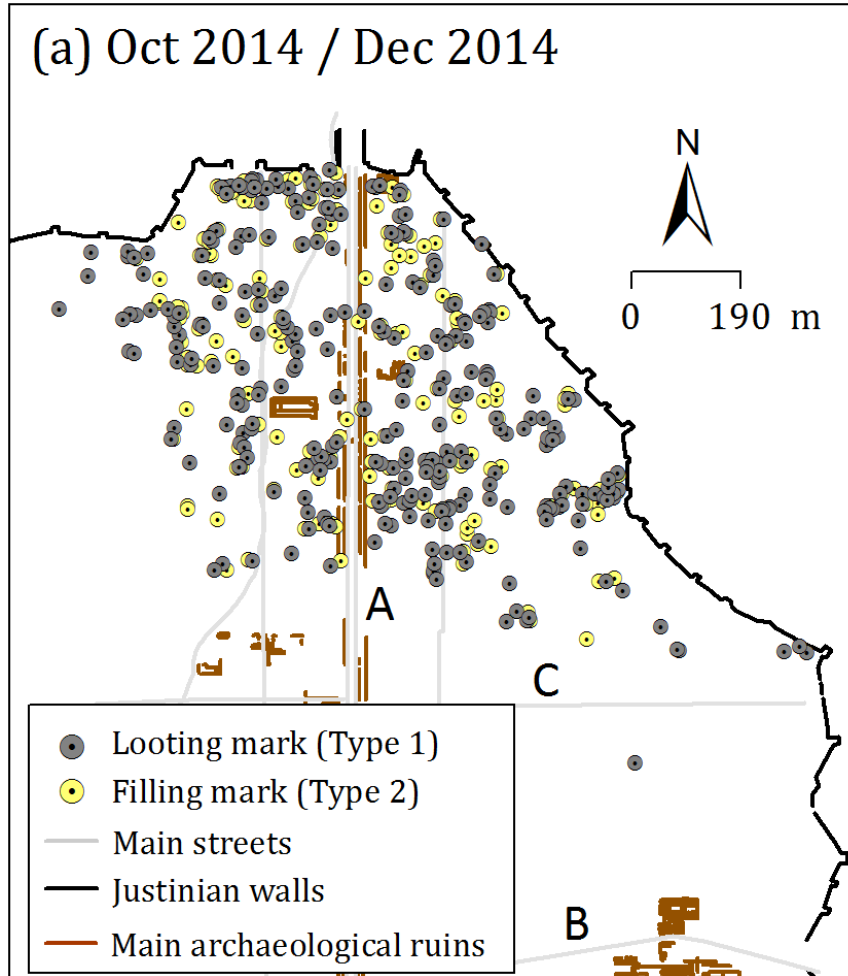
TAPETE *et al.* (2016), Remote Sensing of Environment

Interpretation key matrix



TAPETE *et al.* (2016), Remote Sensing of Environment

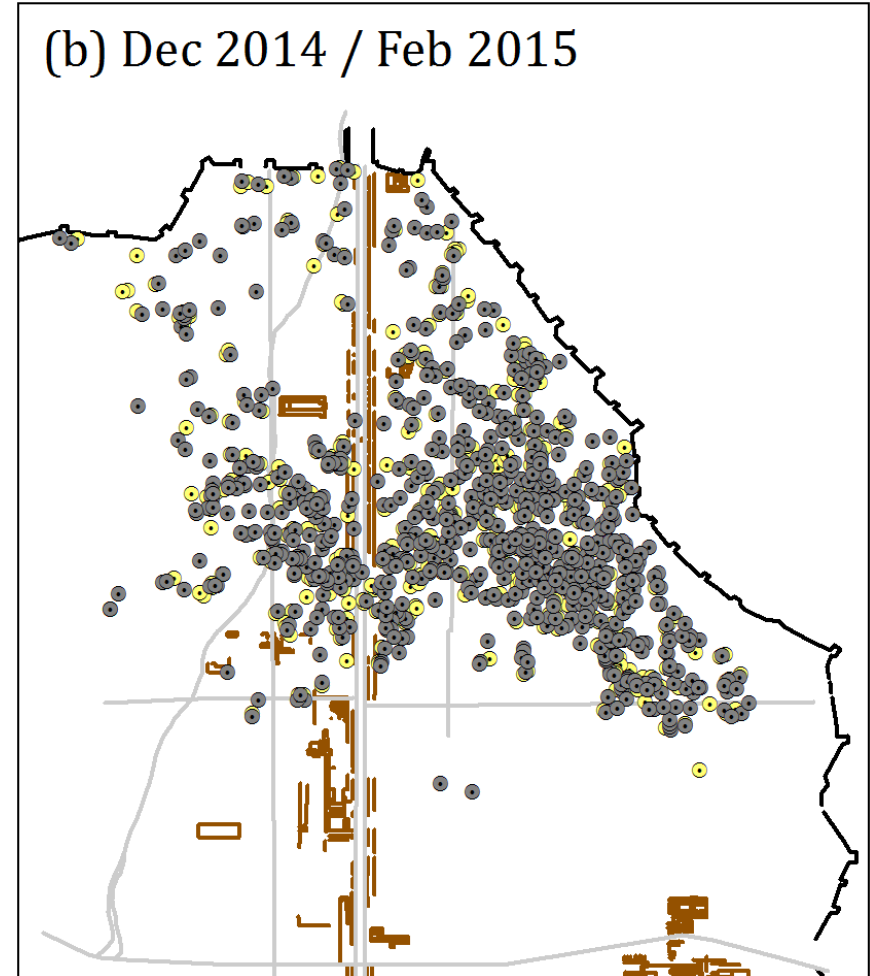
Dynamic assessment of looting rates



132 looting marks/month (Type 1)

82 filling marks/month (Type 2)

Tot.: 214 marks/month



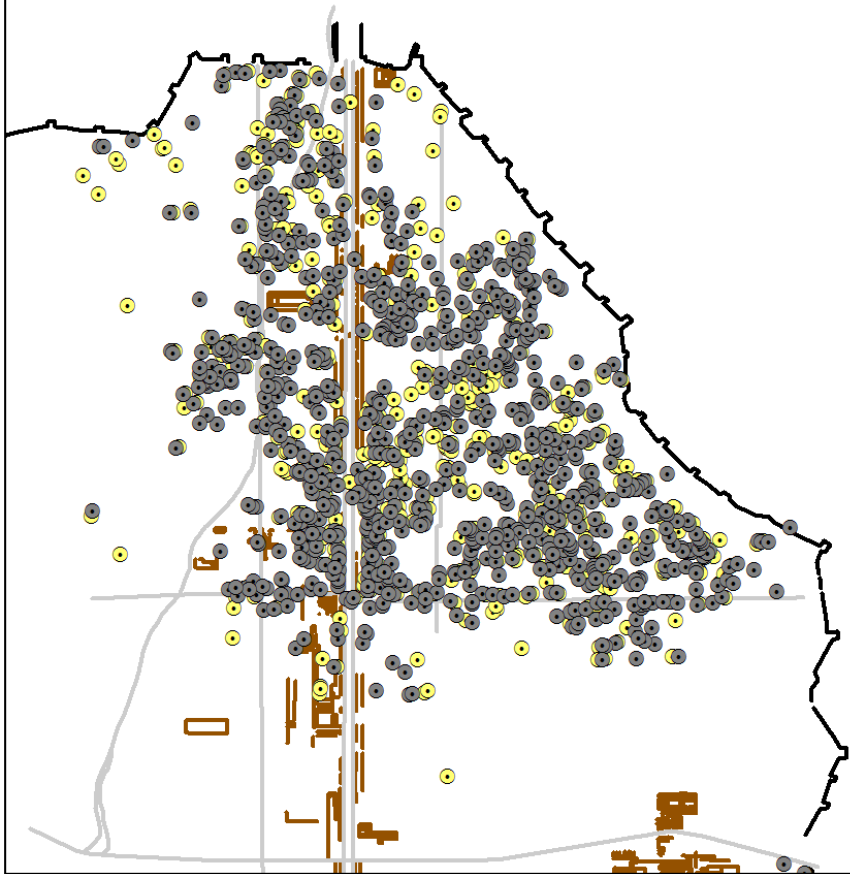
420 looting marks/month (Type 1)

235 filling marks/month (Type 2)

Tot.: 655 marks/month

Dynamic assessment of looting rates

(c) Apr 2015 / Feb 2015

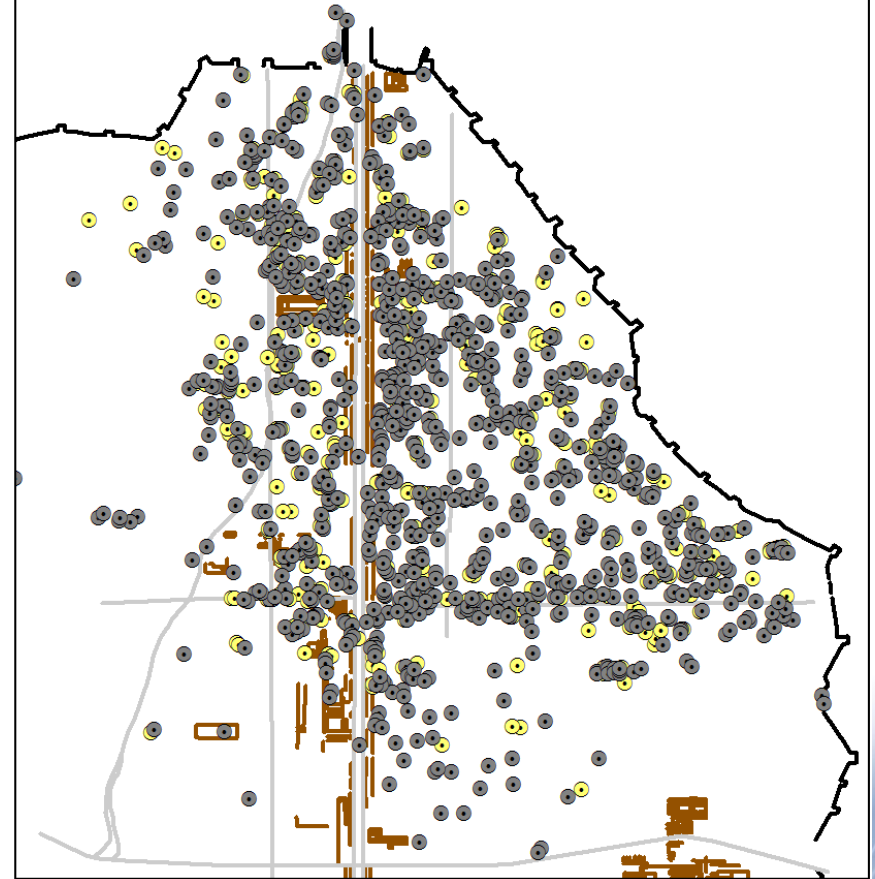


432 looting marks/month (Type 1)

255 filling marks/month (Type 2)

Tot.: 687 marks/month

(d) Jun 2015 / Apr 2015



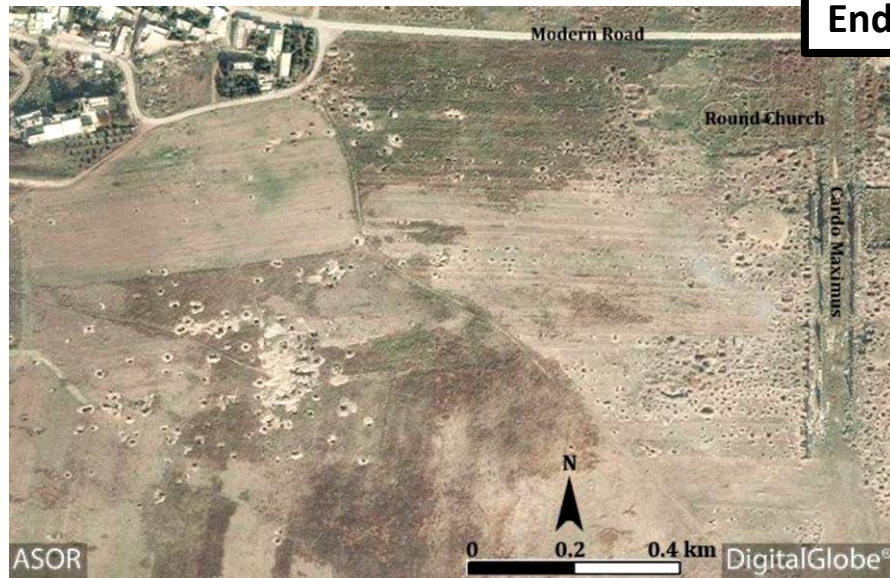
535 looting marks/month (Type 1)

245 filling marks/month (Type 2)

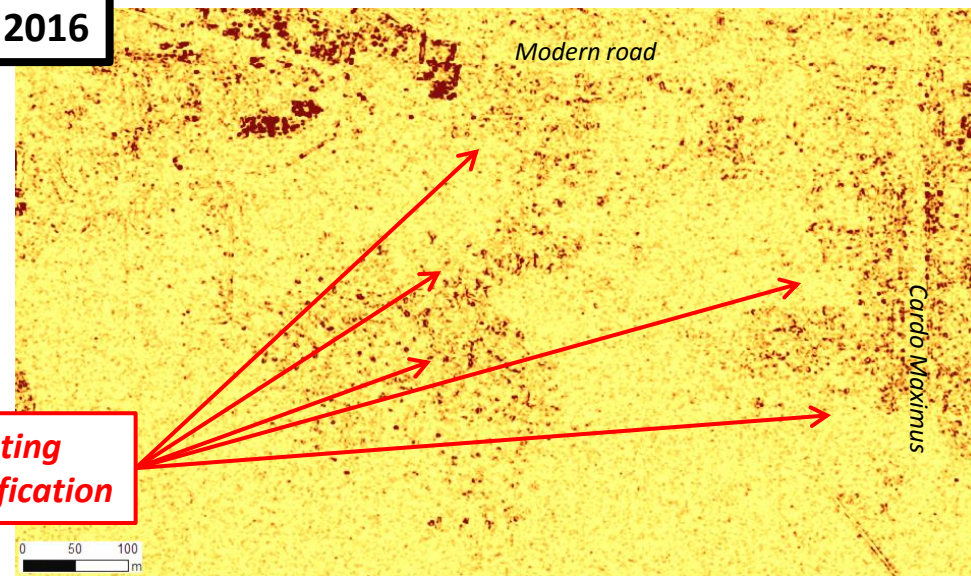
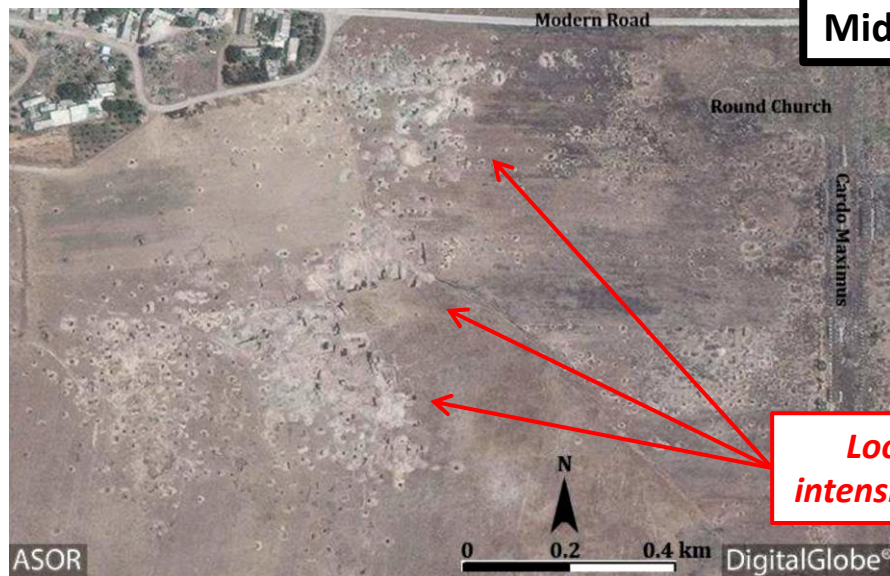
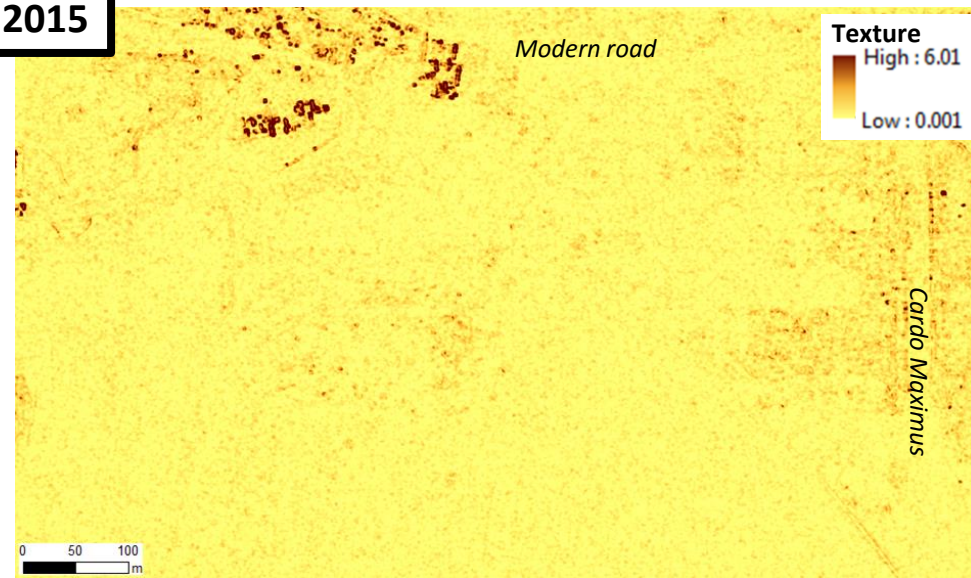
Tot.: 780 marks/month

Looting in 2015 vs. 2016

Optical perspective



Radar perspective



Looting intensification

Dura Europos



Dura Europos



© Marsyas 2008

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Archaeological ruins

© umbrella.it

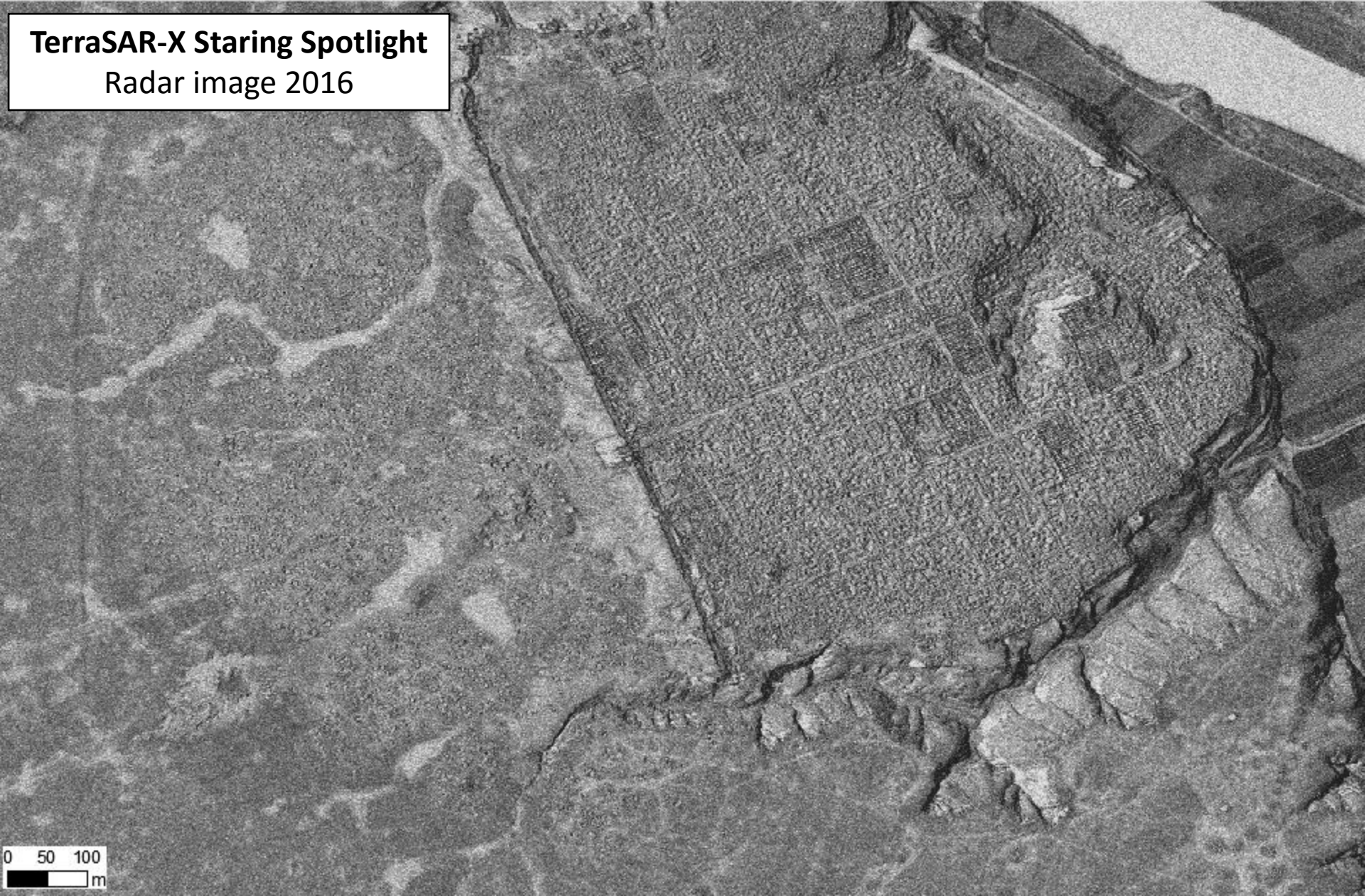


Icons in the Jewish Synagogue (~244 A.D.)

© heorthodoxlife.wordpress.com

Dura Europos

TerraSAR-X Staring Spotlight
Radar image 2016

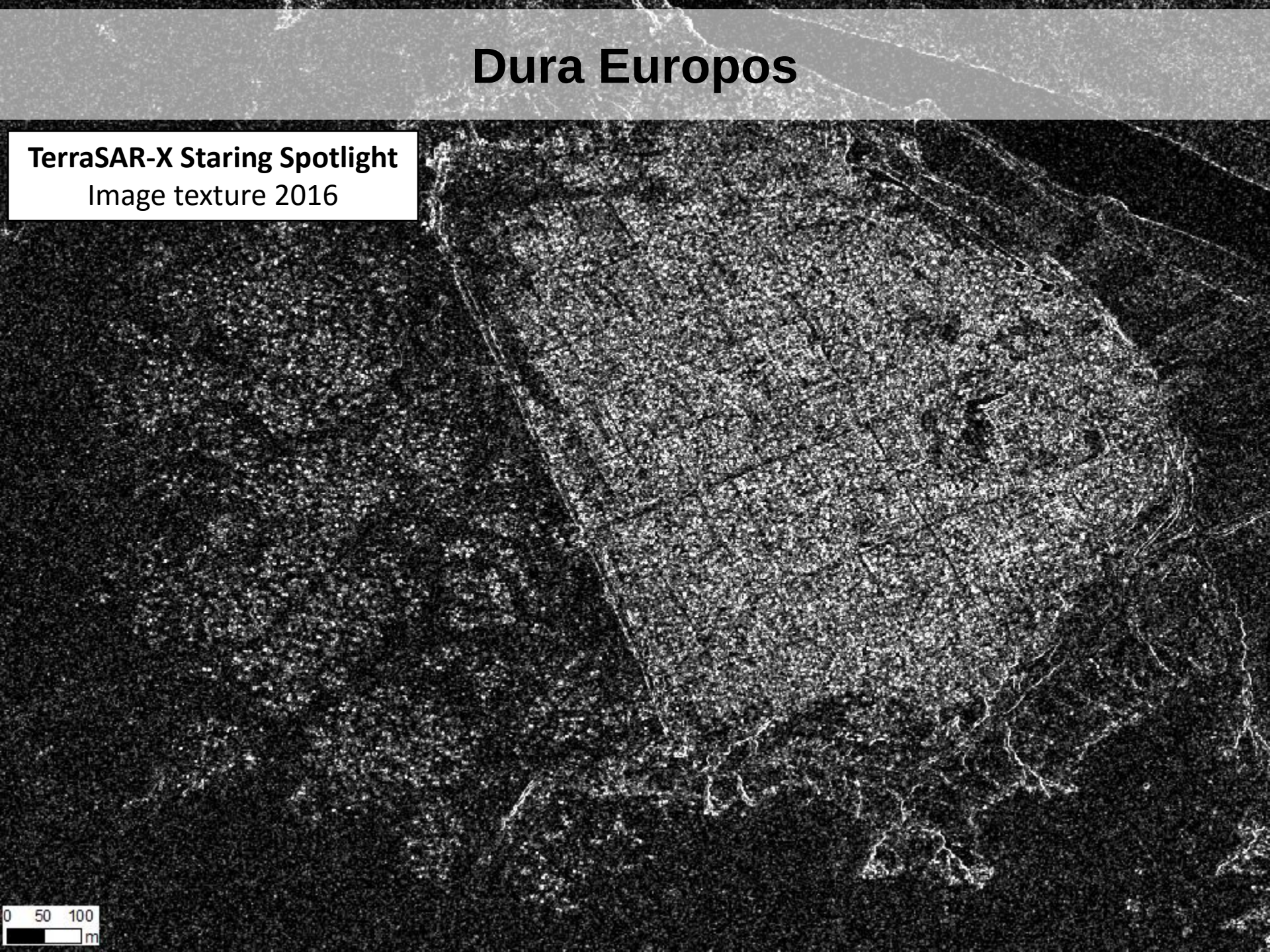


0 50 100
m

Dura Europos

TerraSAR-X Staring Spotlight
Image texture 2016

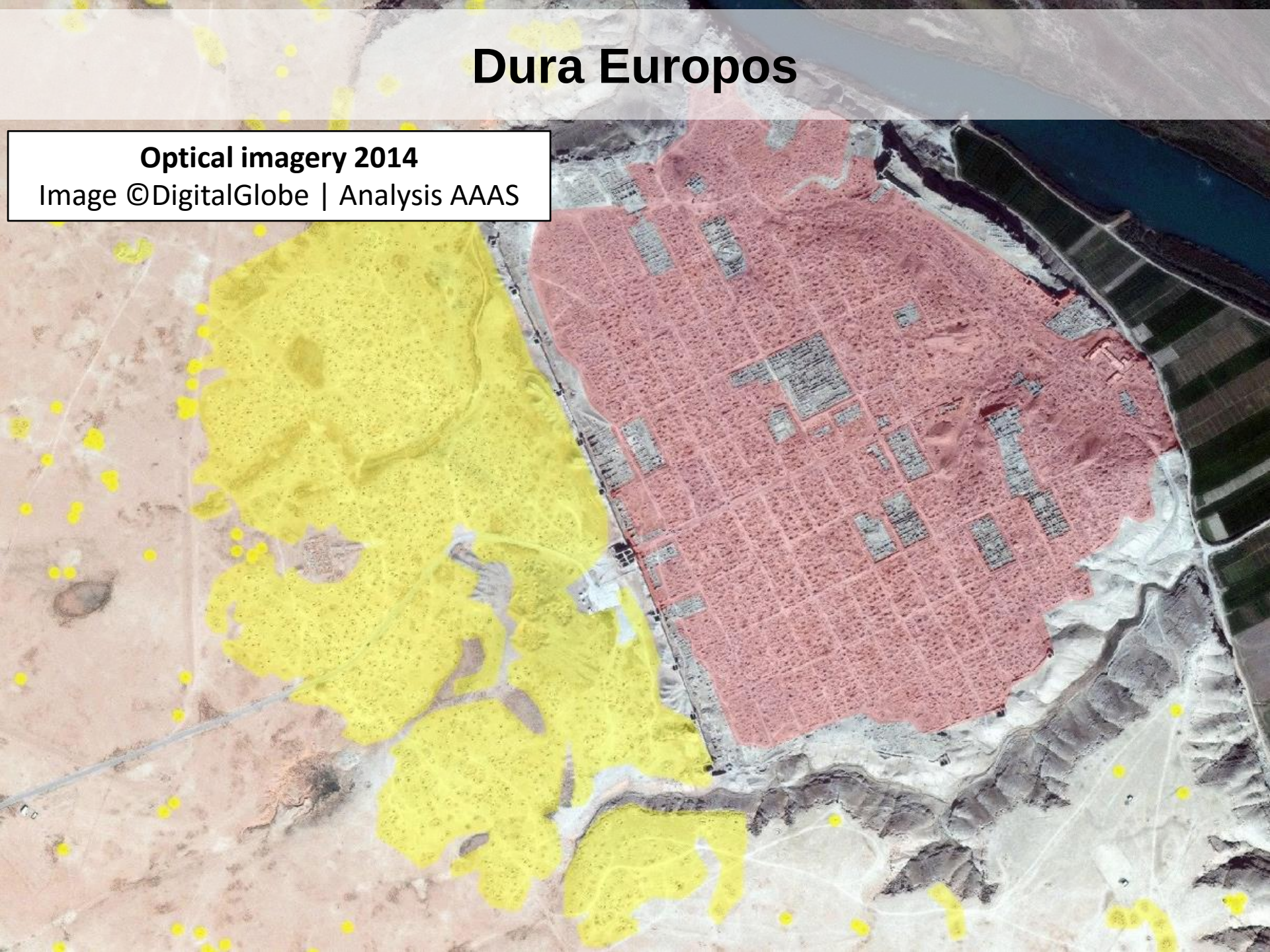
0 50 100
m



Dura Europos

Optical imagery 2014

Image ©DigitalGlobe | Analysis AAAS



Conclusions and future perspectives

Current scenario in satellite SAR science for archaeology

- SAR is not affected by weather conditions, hence monitoring campaigns are largely weather-independent in both arid and humid regions, overcoming limitations of optical imagery (occasionally cloud covered)
- TerraSAR-X Starting Spotlight (< 1 m) brings radar to resolution levels close to those of optical imagery (e.g. QuickBird, GeoEye)

Non-invasive analysis of VHR satellite radar imagery offers novel opportunities

- Digital recording and prospection (feature detection, delineation and mapping; discovery of semi-buried structures; palaeo-environmental studies)
- Conservation and preservation (looting monitoring and damage assessment; condition assessment; safeguarding from natural and anthropogenic geohazards; environmental landscape evolution)



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TAPETE D. & CIGNA F. (2016). Trends and perspectives of space-borne SAR remote sensing for archaeological landscape and cultural heritage applications. *Journal of Archaeological Science: Reports*, doi: 10.1016/j.jasrep.2016.07.017

TAPETE D., CIGNA F., DONOGHUE D. (2016). 'Looting marks' in space-borne SAR imagery: Measuring rates of archaeological looting in Apamea (Syria) with TerraSAR-X Staring Spotlight. *Remote Sensing of Environment*, 178, 42–58.