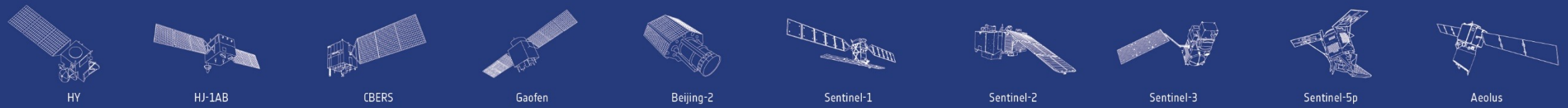

2023 DRAGON 5 SYMPOSIUM

3rd YEAR RESULTS REPORTING

11-15 SEPTEMBER 2023

PROJECT ID. 58113

SARCHAEOLOGY: EXPLOITING SATELLITE SAR FOR ARCHAEOLOGICAL PROSPECTION AND HERITAGE SITE PROTECTION

14/09/2023, 11:00AM - 11:45AM

ID. 58113

PROJECT TITLE: SARCHAEOLOGY: EXPLOITING SATELLITE SAR FOR ARCHAEOLOGICAL PROSPECTION AND HERITAGE SITE PROTECTION

PRINCIPAL INVESTIGATORS:

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PRESENTED BY: PROF. TIMO BALZ [PI CHINA]

Project's objectives

- Exploiting satellite SAR imagery and advanced processing methods for archaeological prospection and heritage sites protection
- Demonstrating the capability of medium to very high-resolution SAR to:
  - ✓ detect (semi-)buried and sub-surface features of archaeological significance
  - ✓ monitor the status and stability of cultural and natural heritage sites and their assets
- Assessing new opportunities and perspectives brought by long-wavelength (e.g., ALOS-1/2 L-band and BIOMASS P-band) and very high-resolution SAR (e.g., IceEye and Paz X-band)
- Focusing on a wealth of heritage asset types: burial mounds, partly buried archaeological ruins, standing monuments within urban centers, natural reserves, paleo-channels and ice patches with organic remains
- Through a range of case study sites in China, Russia, Mongolia, Italy, Norway and Turkey

EO Data Delivery

Data access (list all missions and issues if any). NB. in the tables please insert cumulative figures (since July 2020) for no. of scenes of high bit rate data (e.g. S1 100 scenes). If data delivery is low bit rate by ftp, insert “ftp”

ESA /Copernicus Missions	No. Scenes
1. TerraSAR-X (ftp)	6
2. RADARSAT-1/2 (ftp)	6
3. DEIMOS-2 (ftp)	160 km^2
4. WorldView/GeoEye/QuickBird (ftp)	40 km^2
5. Pléiades-1, RapidEye-1/5, IKONOS-2, Kompsat-2, WV-2 (ESA Collections)	27
6. PlanetScope, Skysat, Pléiades, WV-2 (external licenses)	600 km^2
7. TerraSAR-X (external licenses)	212
8. COSMO-SkyMed (external licenses)	410
Total:	
Issues:	

ESA Third Party Missions	No. Scenes
1. Sentinel-1	906
2. Sentinel-2	47
3.	
4.	
5.	
6.	
Total:	
Issues:	

Chinese EO data	No. Scenes
1. Jilin-1	1
2.	
3.	
4.	
5.	
6.	
Total:	
Issues:	

Project's results after 3 years of activity

- **State-of-the-art review** of heritage applications of imaging radar (see list of published papers)
- Multi-sensor SAR and optical **data collection and tailored tasking** of new acquisitions over the study sites (Dragon-5 ESA TPM quotas, and also from collaborating data grants by ASI, DLR and ESA)
- **EO data processing** with feature extraction, image classification, change detection and InSAR methods
- **Analysis and interpretation, ground truthing and validation** of EO-based evidence and observations
- **Support for cultural heritage protection after the 2023 Turkey** Earthquake by using high-resolution TerraSAR-X data and Sentinel-1 data
- **Main project activities :**
  1) Province of Rome: InSAR to identify subsidence threats to heritage assets
  2) Province of Rome: detectability of buried archaeological features in SAR imagery
  3) Wuhan: InSAR to estimate risks for local cultural heritage sites due to surface deformation
  4) Wuhan: SAR and Keyhole imagery for urban development and induced risk for heritage
  5) Wuhan: simulation of looting pits and analysis of their detectability in high-resolution SAR imagery
  6) Turkey: high-resolution image interpretation and coherence change detection for damage detection, especially with respect to cultural heritage

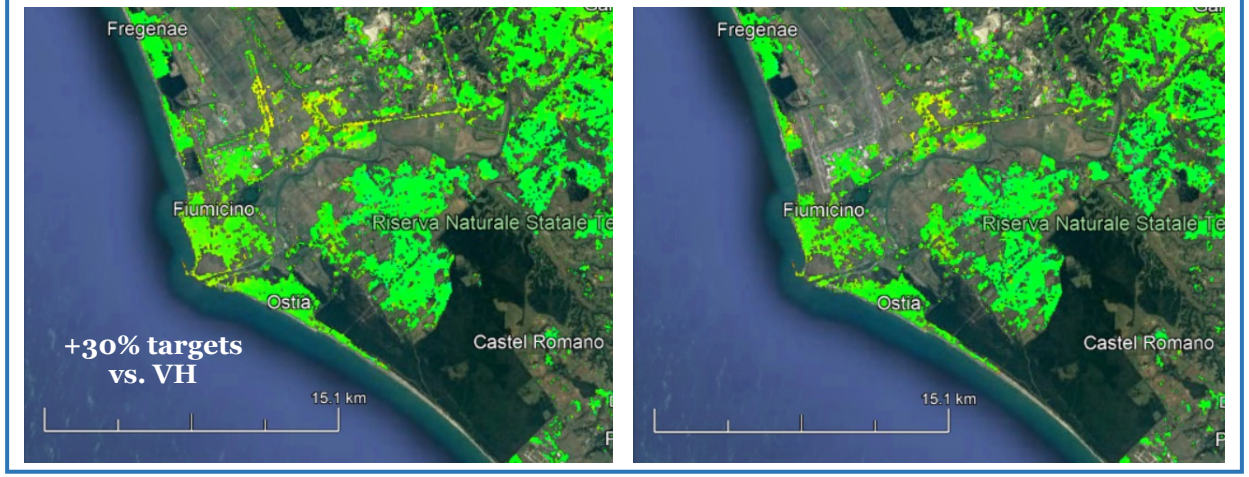
#1: Province of Rome:
InSAR to identify subsidence threats to heritage assets

- **Type of heritage**: standing monuments, exposed archaeological remains and linear structures, spread across urban, sub-urban and rural landscapes of the province (5,363 km²)
- **Scientific goal**: to estimate present-day ground stability and any deformation pattern potentially threatening heritage assets
- **EO data used**: > 500 Sentinel-1 IW mode SAR scenes, dual pol. (VV,VH), tracks T22 descending and T117 ascending
- **Method**: multi-temporal InSAR, Small BAseline Subset (SBAS), parallelised processing chains and HPC infrastructure (ESA's GEP)
- **In-situ data**: site photographs of assets and evidence of structural damage
- **Key results**:
  - 2018-2022 ground displacement rates and time series for coherent targets across Latium Region (17,242 km²)
  - Hotspots mapping at significant land deformation (subsidence) involving monuments and heritage assets
  - Comparison of the performances of 2019-2021 SBAS InSAR using the VV and VH channels (at equal conditions, no. of scenes, thresholds)

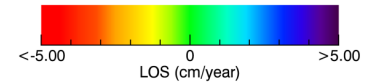
[source: Cigna et al. 2023 GSIS Dragon-5 paper]

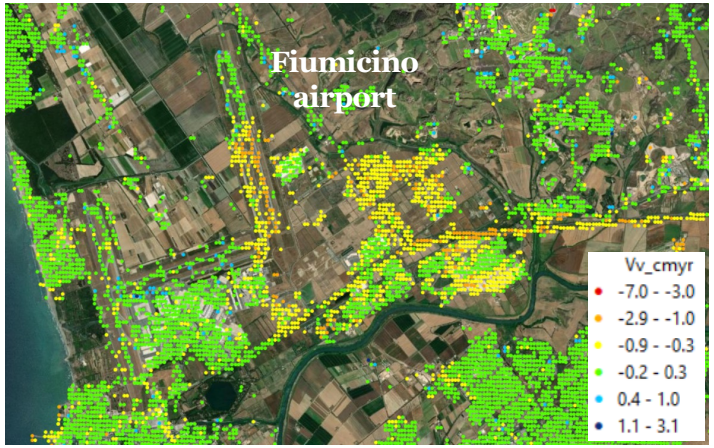
LOS displacement rates in Aug 2019 – Jul 2021
106 S1A/B scenes, T117 ascending

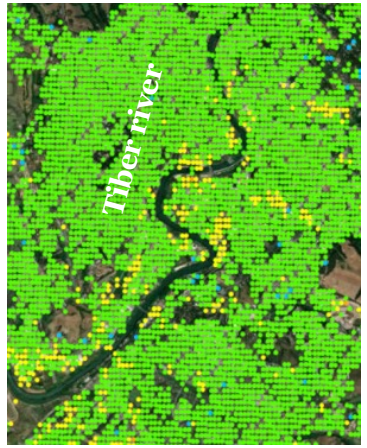
<u>VV channel</u> (~456,000 targets) <u>VH channel</u> (~350,000 targets)



Ground instability hotspots

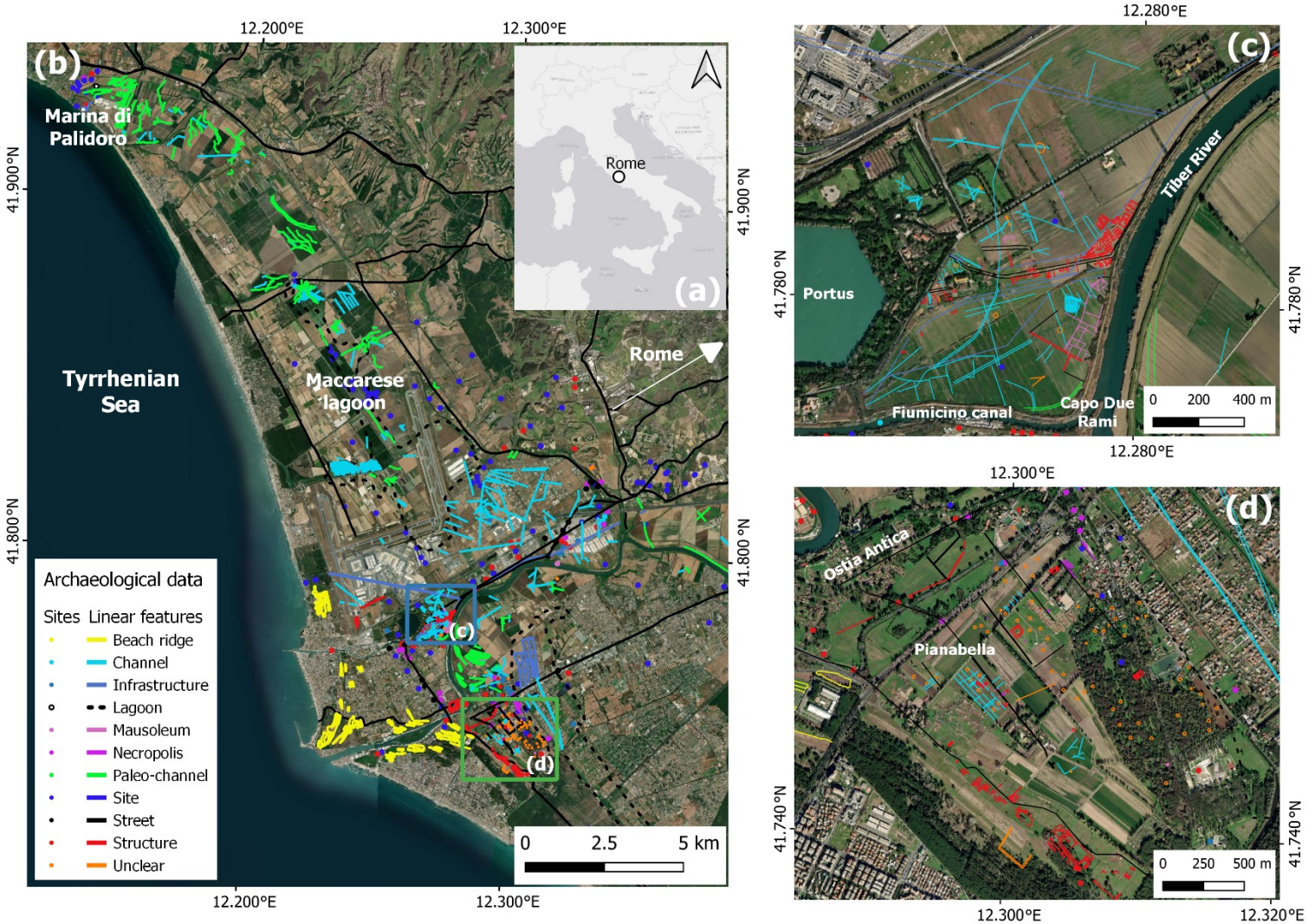






#2: Province of Rome:
detectability of buried archaeological features in SAR imagery

- **Type of heritage**: (semi-)buried archaeological remains across the sub-urban and rural landscapes of Ostia-Portus
- **Scientific goal**: to test the capability of multi-band SAR to detect archaeological features, aided by VHR optical imagery
- **EO data used**:
  - SAR: C-band RADARSAT-2 and Sentinel-1 IW, X-band COSMO-SkyMed Enhanced SpotLight, and L-band ALOS-1 data
  - optical: DEIMOS-2, WorldView-3, Pléiades-1 and Google Earth VHR optical imagery
- **Method**: image interpretation, temporal and spatial filtering, feature extraction, classification, spectral indices
- **In-situ data**: vegetation status, ploughing/harvesting activity, crop/soil marks visibility
- **Key result**: generation of an archaeological database with >1600 mapped features

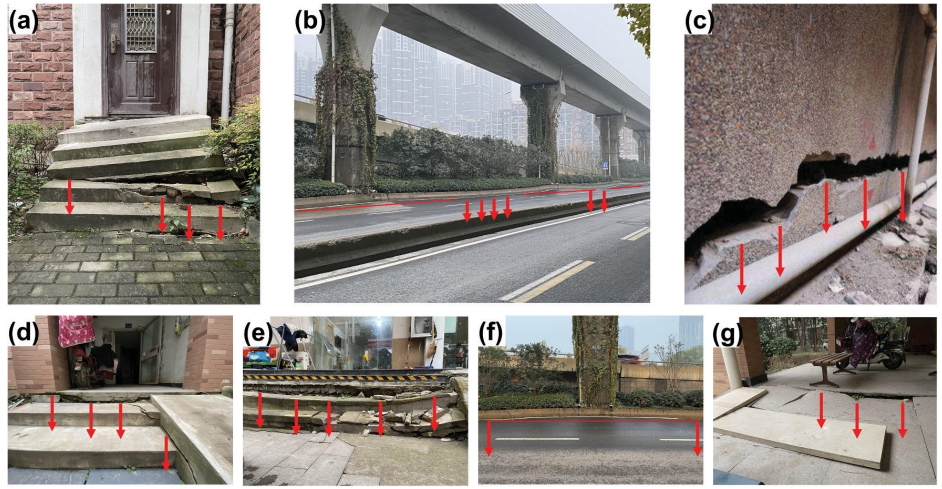


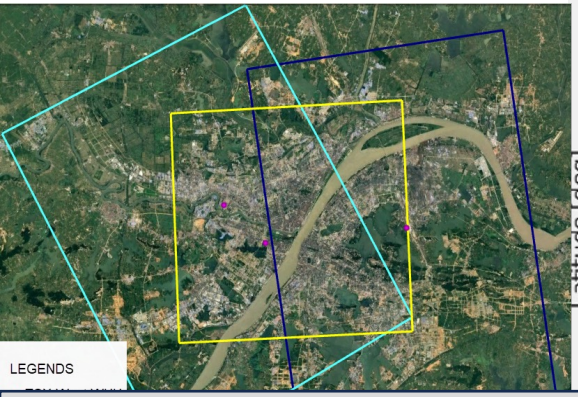
Mapped archaeological sites and linear features, with zoomed views over two key sectors. Output database includes: 515 structures, 401 canals, 268 paleo-channels, 89 beach ridges, 87 streets, 58 mausoleums, 48 necropolises, 259 sites [source: Cigna et al. 2023 GSIS Dragon-5 paper]

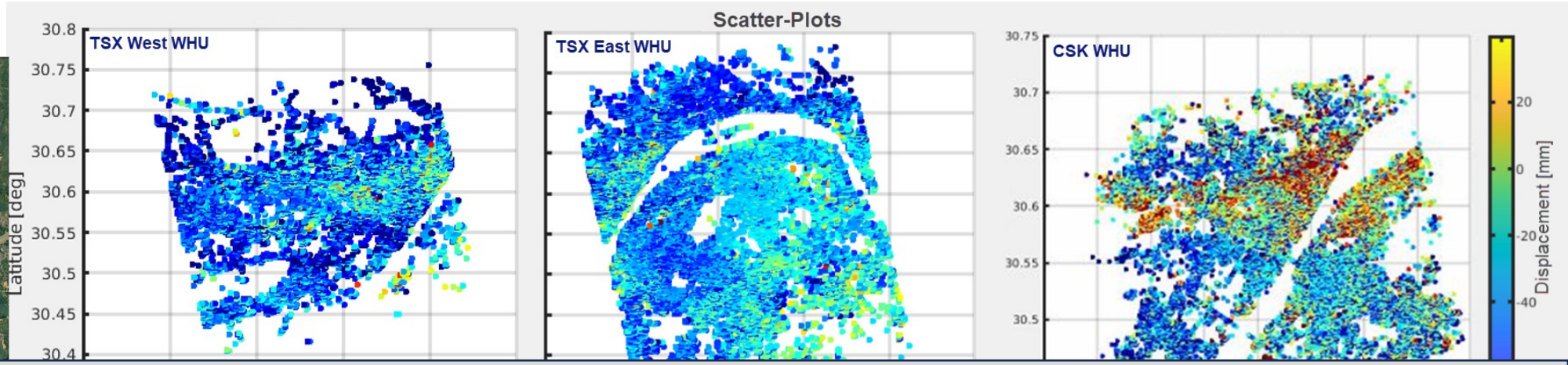
#3: Wuhan: InSAR to estimate risks for local cultural heritage sites due to surface deformation

- **Type of heritage:** Mostly colonial era buildings, World War heritage from the battle of Wuhan and Mao era heritage
- **Scientific goal:** Long-term deformation estimation and data fusion
- **EO data used**: COSMO SkyMed and TerraSAR-X
- **Method:** Non-linear PSInSAR

- **Key results**:
  - Different students working with different approaches and different data sets
  - Comparably huge differences in their results
  - PSInSAR and related methods show ambiguities and parameter selection problems
  - These are especially challenging in long-term observation scenarios



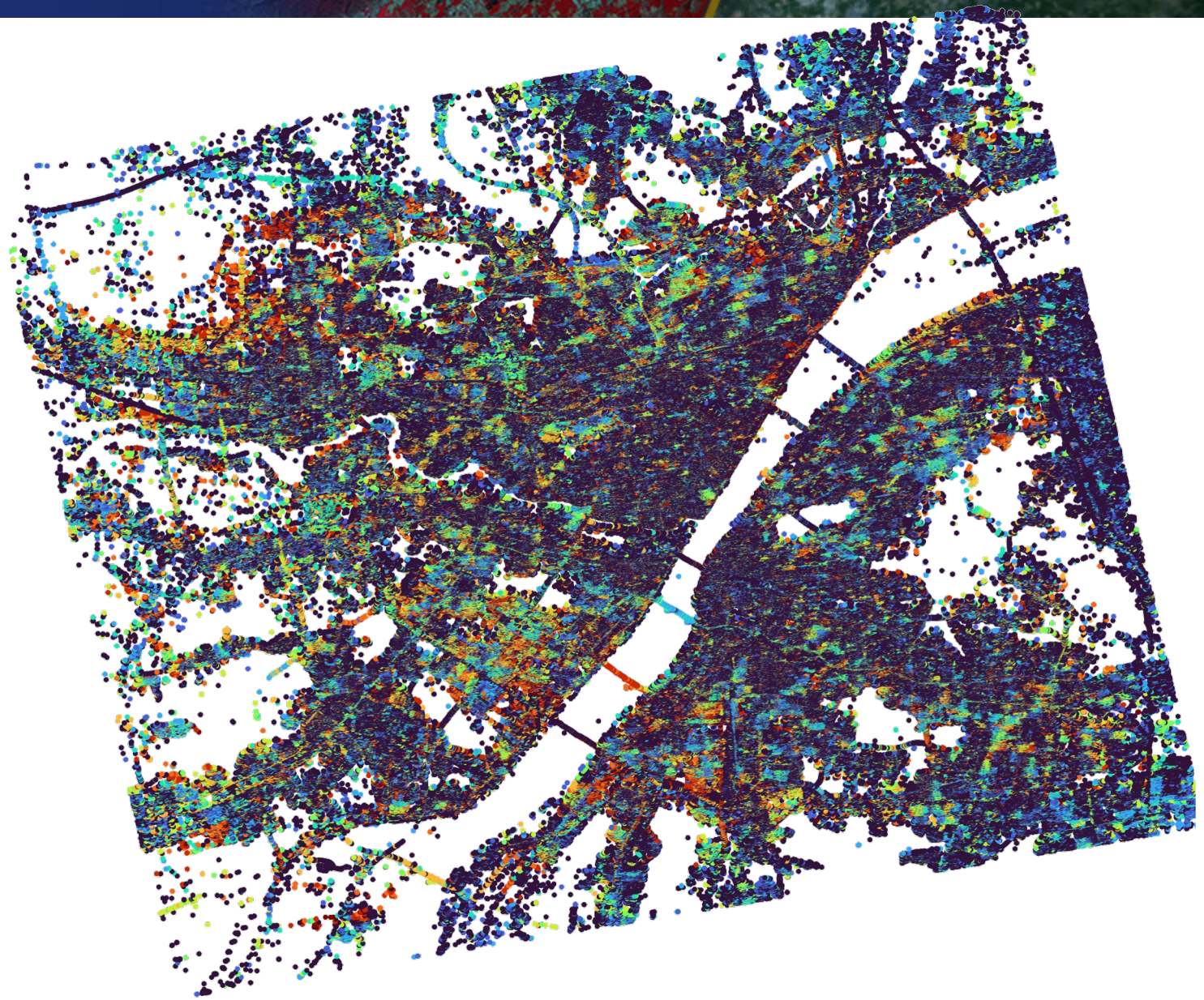




See Poster ID 222: Sadiq et al, Long-term urban subsidence analysis using PSInSAR in Wuhan

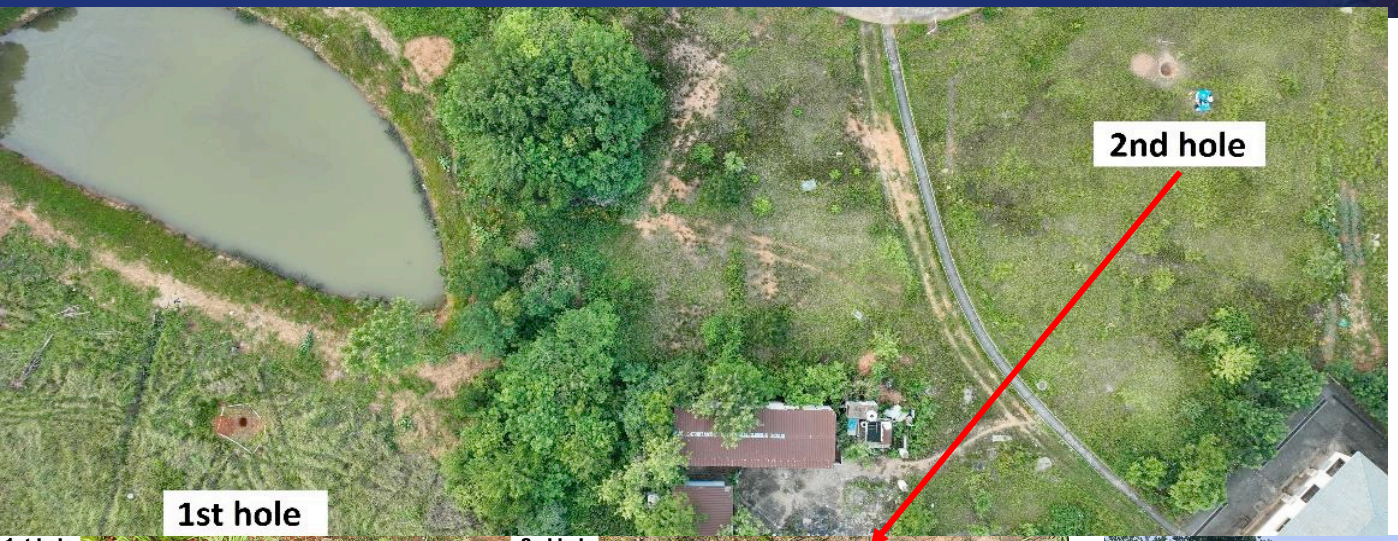
#4: **Wuhan:** SAR and Keyhole imagery for urban development and induced risk for heritage

- **Type of heritage:** Mostly colonial era buildings, World War heritage from the battle of Wuhan and Mao era heritage
- **Scientific goal:** Monitoring the urban development in Wuhan, especially the vertical development with multi-baseline InSAR
- **EO data used:** COSMO SkyMed and TerraSAR-X
- **Method:** Temporal and multi-temporal PS identification and dynamic tPS height identification
- **In-situ data: Field work data**



#5: Wuhan: simulation of looting pits and analysis of their detectability in high-resolution SAR imagery

#5: **Wuhan:** simulation of looting pits and analysis of their detectability in high-resolution SAR imagery

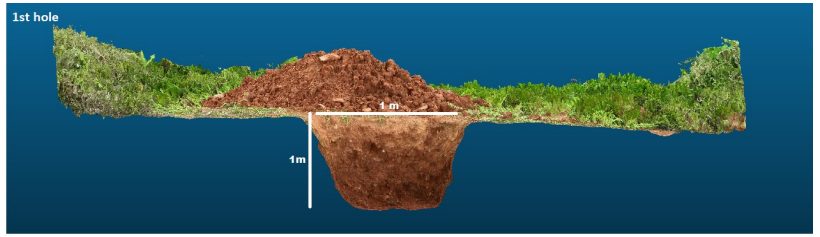


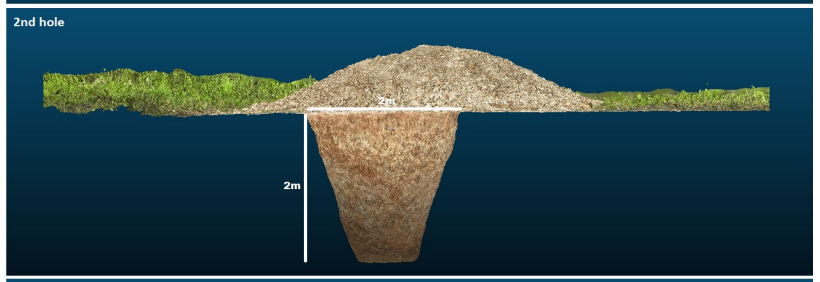
Type of heritage: Looting indicators

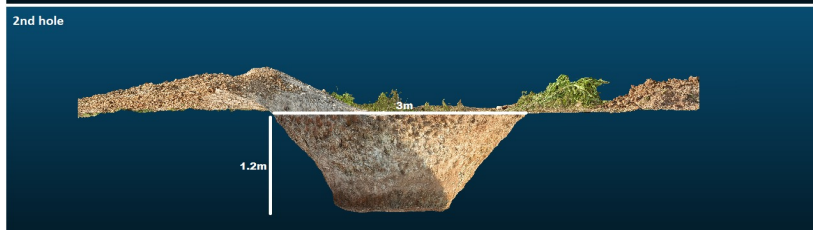
Scientific goal: Determine detectability of looting sites in SAR data

EO data used: TerraSAR-X high resolution data, UAV images

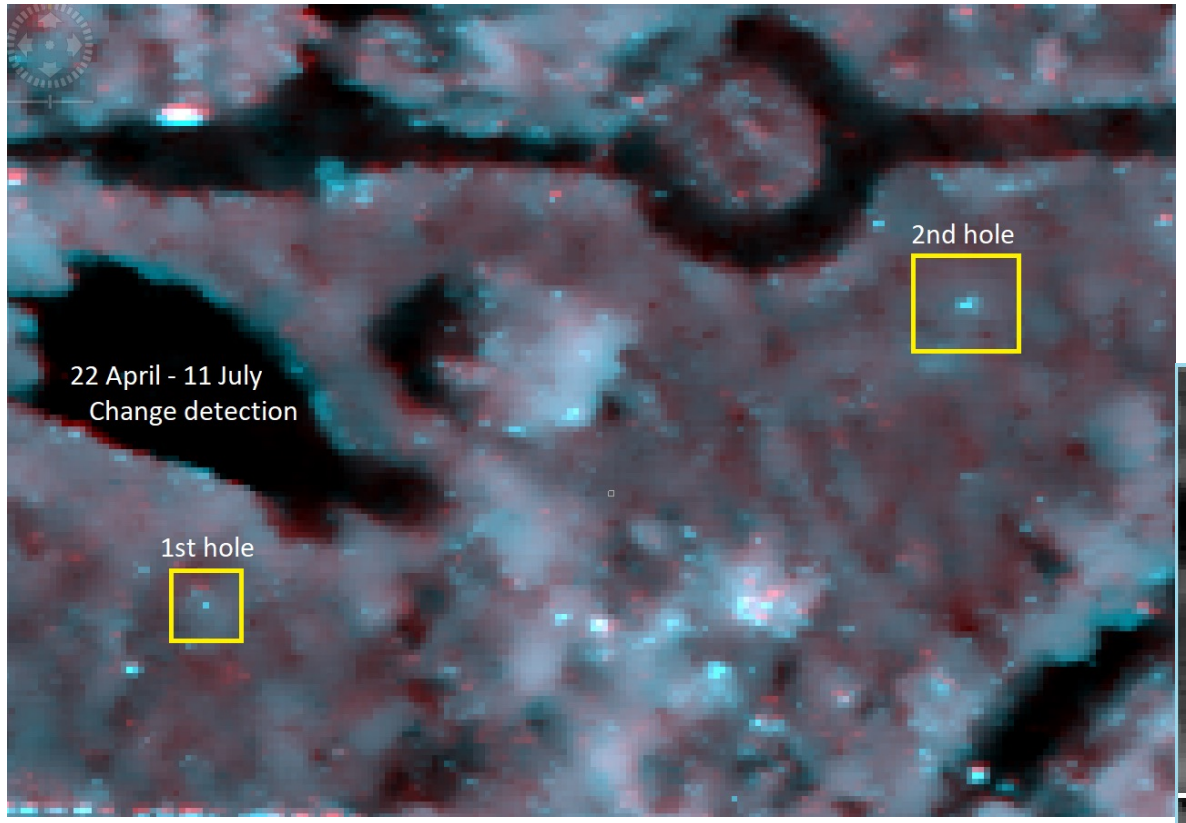
Method: image interpretation, machine learning, coherence change detection





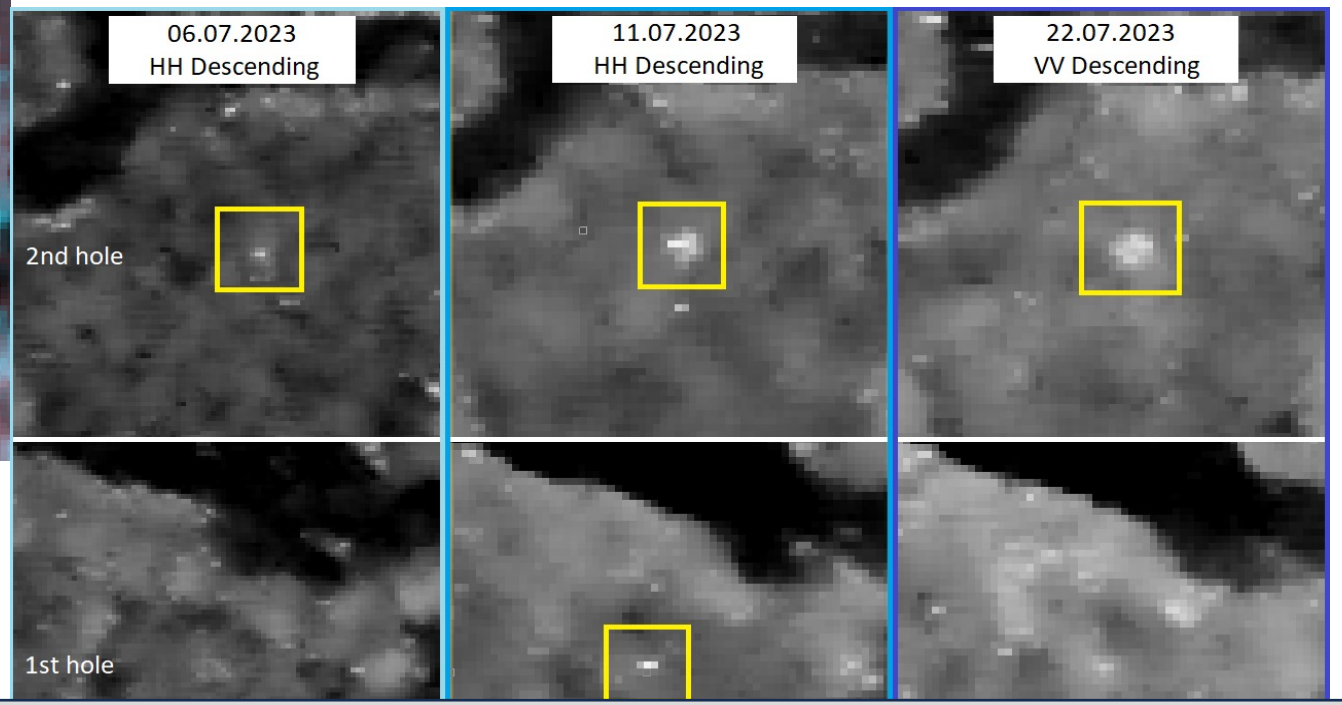


#5: Wuhan: simulation of looting pits and analysis of their detectability in high-resolution SAR imagery (2)



Date	Orbit	Polarization	Incident Angle	Hole Size (m) 1st	Hole Size (m) 2nd	Visibility 1st	Visibility 2nd
4.06.2023	Ascending	HH	50.15	1x1		Not visible	Not Visible
8.06.2023	Descending	VV	29.12	1x1	2x1	Not visible	Barely V.
14.06.2023	Descending	HH	45.52	1x1	2x1.7	Not visible	Barely V.
15.06.2023	Ascending	VV	50.15	1x1	2x1.7	Not visible	Not Visible
19.06.2023	Descending	VV	29.14	1x1	2x2	Not visible	Not Visible
6.07.2023	Descending	HH	45.5	1x1	2x1.6	Not visible	Visible
7.07.2023	Ascending	VV	50.16	1x1	2x1.6	Not visible	Not Visible

- **Key results**:
  - Detection of smaller holes difficult
  - Orbit parameters are very important
  - 2 x 2 m seems to be relatively well detectable in high-resolution imagery



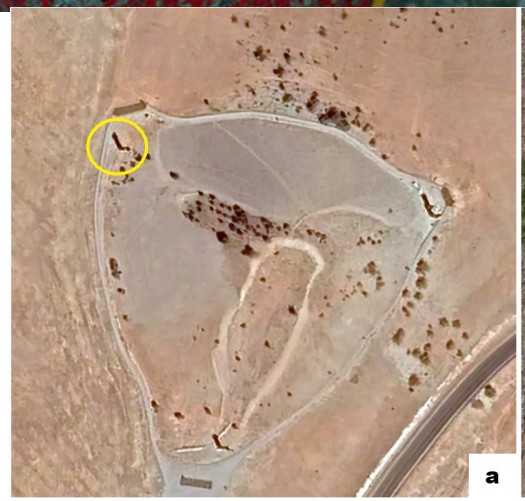
See Poster ID 154: Boyoglu et al, Verifying the detectability of small-scale looting in SAR images

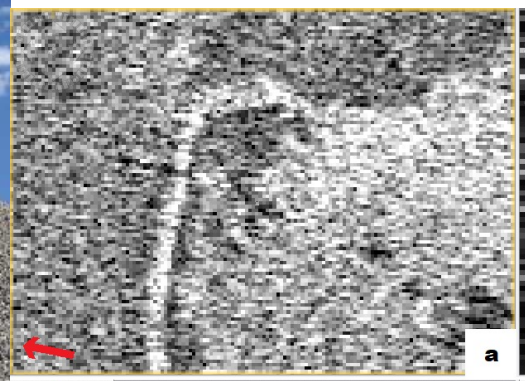
#6: Turkey: detection of damages to cultural heritage caused by the 2023 Turkey Earthquake

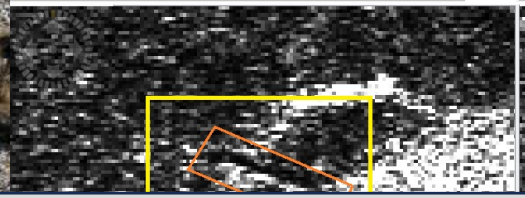
- **Type of heritage**: Various heritage sites (Mosques, churches, castles, etc.)
- **Scientific goal**: Identify damages to cultural heritage sites from different SAR systems
- **EO data used**: Sentinel-1 IW mode SAR scenes, dual pol. (VV,VH), and VHR TerraSAR-X images
- **Method**: visual interpretation and coherence change detection
- **In-situ data**: site photographs and UAV data from local colleagues
- **Key results**:
  - Widespread damage to cultural heritage sites
  - Visual interpretation of high-resolution SAR data often difficult and ambiguous
    - No TSX pre-event archive data available
  - Multi-orbit analyzes is recommended
  - Thanks to the archive data of Sentinel-1, good results can be achieved from Sentinel-1 coherence change detection

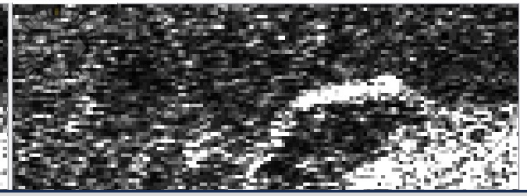
#6: **Turkey:** detection of damages to cultural heritage caused by the 2023 Turkey Earthquake (2)

- **Type of heritage**: Columns
- **EO data used**: Multi-orbit VHR TerraSAR-X images
- **Method**: visual interpretation







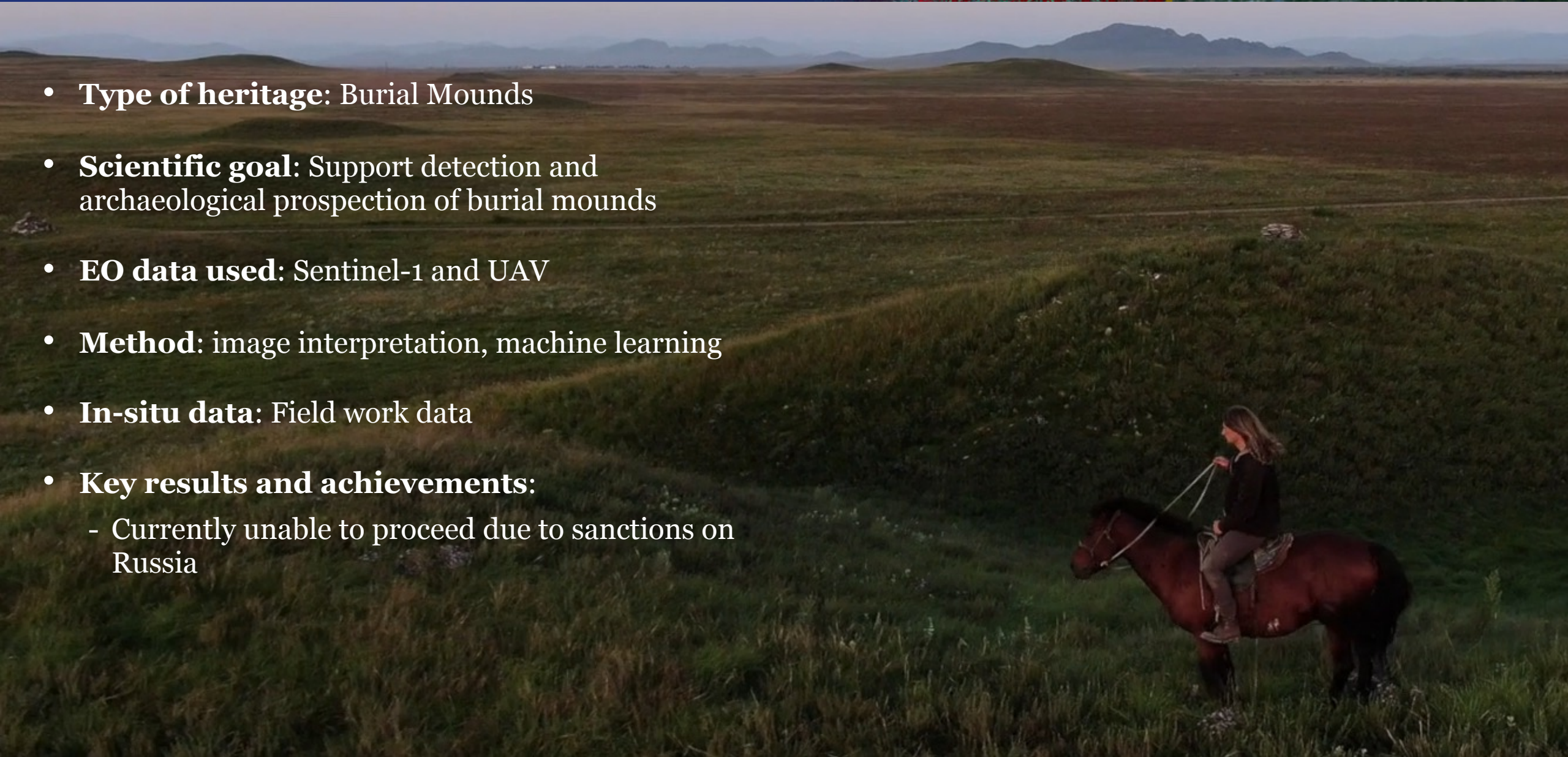


- **Key results**:
  - Detectability strongly depended on the orbit parameters
  - Quick glance can confuse the collapsed column with radar shadow
  - Damage not visible from some orbits
  - Collapse clearly identifiable from

See Poster ID 152: Ifeanyi et al, Assessing the impact of the 2023 Turkey earthquake on cultural heritage

#0: Tuva Republic: improving methodologies and monitoring burial mounds (cancelled)

- **Type of heritage**: Burial Mounds
- **Scientific goal**: Support detection and archaeological prospection of burial mounds
- **EO data used**: Sentinel-1 and UAV
- **Method**: image interpretation, machine learning
- **In-situ data**: Field work data
- **Key results and achievements**:
  - Currently unable to proceed due to sanctions on Russia



European Young scientists' contributions in Dragon 5

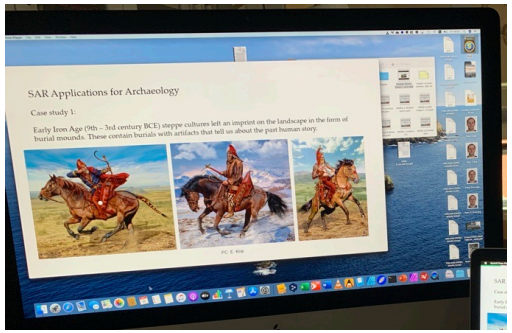
Name	Institution	Poster title	Contribution including period of research
Mr. Michele Abballe	CNR-ISAC	n/a	• 1 year-long postgraduate research fellowship on archaeological mapping through optical and SAR imagery [Apr 2022 – Mar 2023] • Trained on optical and SAR data analysis and interpretation • Attended 2nd InnEO Summer School on machine learning for EO, featuring ESA and ASI lecturers [25-29 Jul 2022] • Presented 1 abstract at the Landscape Archaeology Conference (LAC 2022) [10-15 Sept 2022] • Co-authored the Dragon-5 Mid Term Reporting paper published in the GSIS Special Issue [Jan-Jul 2023]
TBC (*under recruitment*)	ASI	n/a	• 3 year-long PhD fellowship on integration of optical and SAR to support sustainable urbanization and urban regeneration design of historic cities threatened by natural hazards [Nov 2023 – Oct 2026]

Chinese Young scientists' contributions in Dragon 5

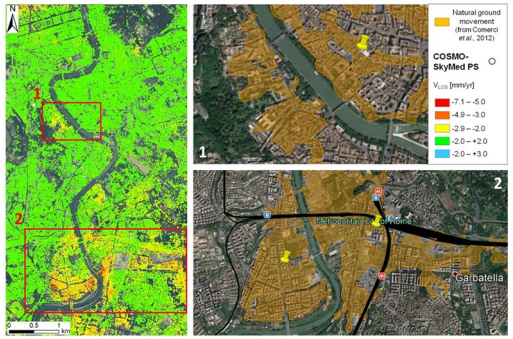
Name	Institution	Poster title	Contribution including period of research
Mr. Haonan Jiang	LIESMARS, Wuhan University	-	• PhD on long-term InSAR measurement • Currently at GFZ Potsdam
Mr. Cem S. Boyoglu	LIESMARS, Wuhan University	Verifying the detectability of small-scale looting in SAR images	• PhD on SAR in archaeology
Mr. Chike Ifeanyi	LIESMARS, Wuhan University	Assessing the impact of the 2023 Turkey earthquake on cultural heritage	• Master on SAR for change detection focusing on artisanal mining in Nigeria
Ms. Sadia Sadiq	LIESMARS, Wuhan University	Long-term urban subsidence analysis using PSInSAR in Wuhan	• PhD on PSInSAR parameter estimation

Project's team training, teaching & dissemination

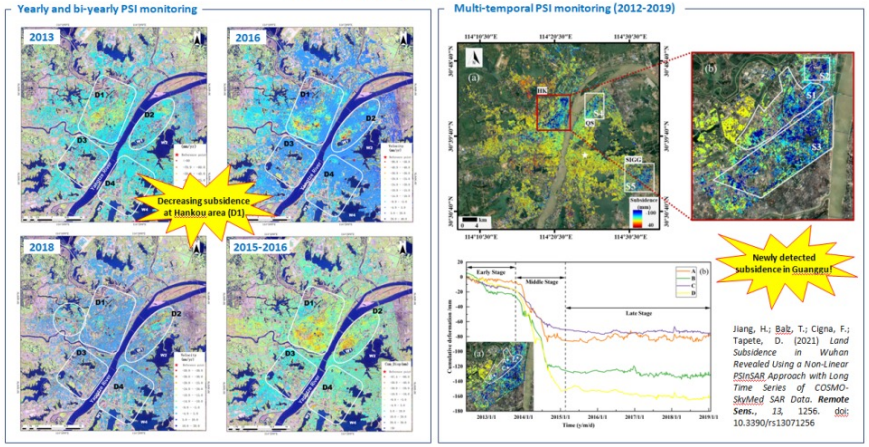
Prof. Timo Balz led the ***Microwave Remote Sensing Course*** at Wuhan University in mid 2020, and Dr. Deodato Tapete and Dr. Gino Caspari gave online lectures on SAR applications for archaeology



Prof. Bihong Fu organized the ***International Workshop on Space Technologies for Disaster Mitigation of World Heritage*** on 13-16 Oct 2020, in Jiuzhaigou, China, and Prof. Timo Balz gave lectures on SAR remote sensing



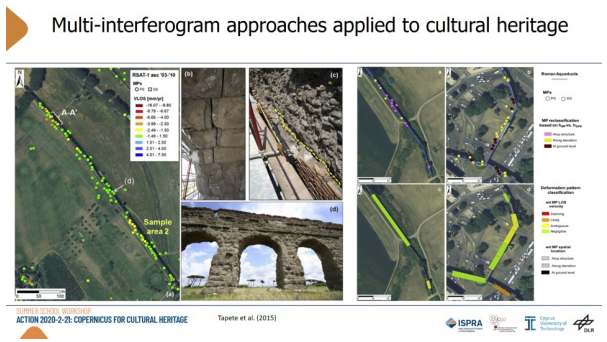
The ASI, Wuhan University and CNR-ISAC teams presented results on monitoring subsidence in Wuhan with InSAR at the **IEEE IGARSS 2021 Symposium** on 12-16 Jul 2021



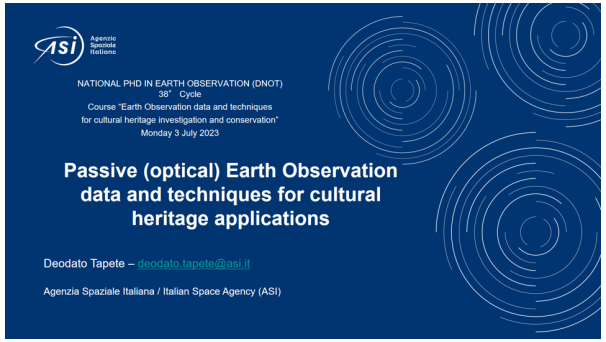
The CNR-ISAC and ASI teams presented results on detecting archaeological features with satellite SAR and optical data at the **7th Landscape Archaeology Conference (LAC)** on 10-15 Sept 2022

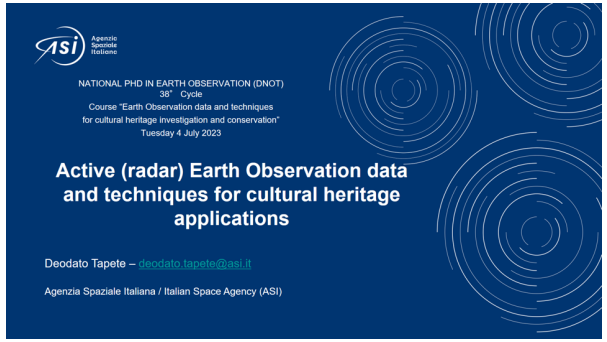
Project's team training, teaching & dissemination

Dr. Deodato Tapete (ASI) gave lectures on SAR change detection and InSAR techniques for study and conservation of cultural heritage, during the **Summer school workshop Action 2020-2-21: Copernicus for cultural heritage** on 13-16 Jun 2023



Dr. Deodato Tapete (ASI) taught on SAR and optical EO for cultural heritage, during the Doctoral Training Course on "*Earth Observation data and techniques for cultural heritage investigation and conservation*", **National PhD in Earth Observation (DNOT)**, 3-6 Jul 2023
(DNOT contributes to the permanent training of young scientists in the framework of Copernicus Academy)





Project's team publications after 3 years

The team published the **Dragon-5 Mid Term Reporting Paper**, within the Special Issue: *ESA and NRSCC Dragon-5 cooperation mid-term results (2020-2022)*

- CIGNA F., BALZ T., TAPETE D., CASPARI G., FU B., ABBALLE M., JIANG H. 2023. **Exploiting satellite SAR for archaeological prospection and heritage site protection**. *Geo-spatial Information Science*, 26 pp. https://doi.org/10.1080/10095020.2023.2223603 [Jul 2023]

GEO-SPATIAL INFORMATION SCIENCE
https://doi.org/10.1080/10095020.2023.2223603

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Exploiting satellite SAR for archaeological prospection and heritage site protection

Francesca Cigna, Timo Balz, Deodato Tapete, Gino Caspari, Bihong Fu, Michele Abballe and Haonan Jiang

ABSTRACT

Optical and Synthetic Aperture Radar (SAR) remote sensing has a long history of use and reached a good level of maturity in archaeological and cultural heritage applications, yet further advances are viable through the exploitation of novel sensor data and imaging modes, big data and high-performance computing, advanced and automated analysis methods. This paper showcases the main research avenues in this field, with a focus on archaeological prospection and heritage site protection. Six demonstration use-cases with a wealth of heritage asset types (e.g. excavated and still buried archaeological features, standing monuments, natural reserves, burial mounds, paleo-channels) and respective scientific research objectives are presented: the Chóra Portus area and the wider Province of Rome (Italy), the city of Wuhan and the Jiuzhaigou National Park (China), and the Siberian "Valley of the Kings" (Russia). Input data encompass both archive and newly tasked medium to very high-resolution imagery acquired over the last decade from satellite (e.g. Copernicus Sentinels and ESA Third Party Missions) and aerial (e.g. Unmanned Aerial Vehicles, UAV) platforms, as well as field-based evidence and ground truth, auxiliary topographic data, Digital Elevation Models (DEM), and monitoring data from geodetic campaigns and networks. The novel results achieved for the use-cases contribute to the discussion on the advantages and limitations of optical and SAR-based archaeological and heritage applications aimed to detect buried and sub-surface archaeological assets across rural and semi-vegetated landscapes, identify threats to cultural heritage assets due to ground instability and urban development in large metropolises, and monitor post-disaster impacts in natural reserves.

ARTICLE HISTORY
Received 27 January 2023
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KEYWORDS
Synthetic Aperture Radar (SAR); interferometric SAR (InSAR); multispectral imagery; cultural heritage; crop mark; archaeological prospection; site monitoring; Unmanned Aerial vehicle (UAV) surveying

1. Introduction

The use of remote sensing for archaeological and cultural heritage applications has a long history, enabling to outline the trajectory that this scientific field has followed over the past century (Luo et al. 2019). In this framework, imaging radar, and in particular, Synthetic Aperture Radar (SAR) technologies, have played a key role in advancing the application field of cultural heritage (Chen et al. 2022). As a discipline, imaging radar has reached such a level of maturity that the stage of proof-of-concept has been successfully passed, and several operational workflows have been established to address user-driven real-world applications in the framework of interdisciplinary approaches (Chen et al. 2021).

It is in this context, wherein both the European and the Chinese scientific communities have consolidated shared technical expertise in SAR for cultural heritage, that the present paper aims to showcase the research avenues that are currently investigated to further advance the exploitation of satellite SAR data for purposes of archaeological prospection and heritage site protection. To better frame the novelty of this paper, a brief account of the current state-of-the-art of SAR remote sensing for heritage applications is first provided (Section 1.1), also in relation to optical remote sensing that is used to complement SAR observations and measurements. Specific scientific objectives of the collaborative research context framing the work are then provided (Section 1.2), toward the presentation of data and methods (Section 2), results and discussion (Section 3), and key conclusions (Section 4).

1.1. Optical and radar imaging for heritage applications: state-of-the-art

In the last decades, Earth Observation (EO) technologies and imagery collected by means of space-borne sensors – mainly operating in the visible, InfraRed (IR), and microwave portions of the electromagnetic spectrum – have been increasingly used for cultural heritage applications. These encompass investigations

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Exploiting satellite SAR for archaeological prospection and heritage site protection

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ABSTRACT

Optical and Synthetic Aperture Radar (SAR) remote sensing has a long history of use and reached a good level of maturity in archaeological and cultural heritage applications, yet further advances are viable through the exploitation of novel sensor data and imaging modes, big data and high-performance

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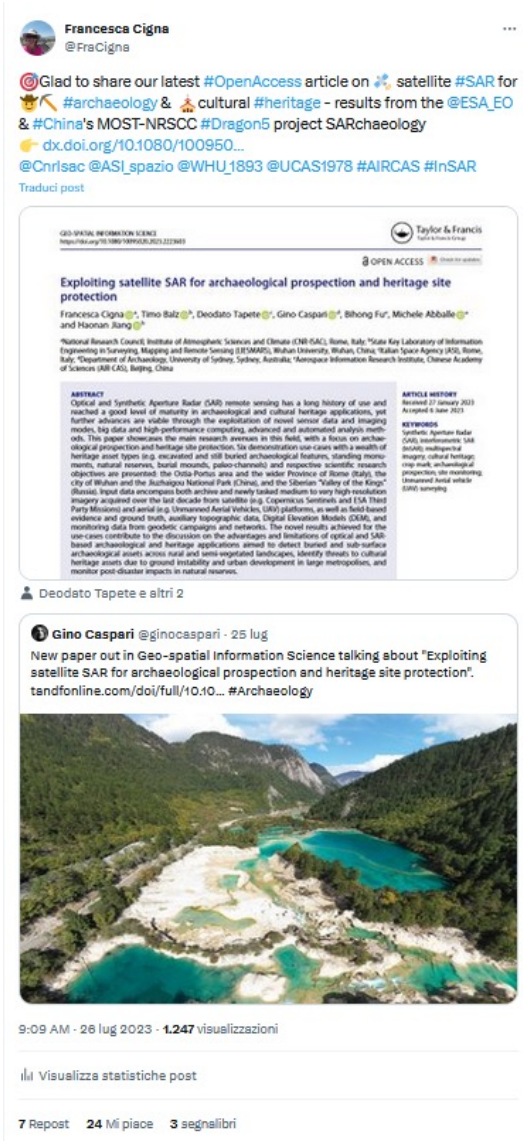

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Exploiting satellite SAR for archaeological prospection and heritage site protection

Deodato Tapete e altri 2

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Project's team publications after 3 years

The team also contributed to **review papers on the use of imaging radar in heritage applications**, and articles on **SAR-based applications in heritage sites worldwide**, in collaboration with a wider network of European and Chinese scientists

- CHEN F., GUO H., TAPETE D., MASINI N., CIGNA F., LASAPONARA R., PIRO S., LIN H., MA P. 2021. Interdisciplinary approaches based on imaging radar enable cutting-edge cultural heritage applications. *National Science Review*, 8 (9), nwab123, https://doi.org/10.1093/nsr/nwab123 [IF = 20.6; Q1 in Multidisciplinary Sciences]
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- CASPARI, G., SCHOU T.P., STEURI, N., BALZ, T. 2023. Glacial Archaeology in Northern Norway—The Island of Seiland. *Remote Sensing*, https://doi.org/10.3390/rs15051336 [IF = 5.0; Q2 in Remote Sensing]

Project's schedule & planning for the 4th year

- Further develop and finalize the ongoing research activities in the Province of Rome, the city of Wuhan and Turkey, and prepare manuscripts for submission to scientific journals in 2024 as well as the final report
- Identify other training and academic exchange opportunities for the Chinese and European YSs to further develop their EO data analysis skills
- Finalize research activities on:
  - UNESCO natural heritage in Jiuzhaigou (China) to detect ground instability, land cover changes and impacts of tourism
  - Threat to cultural heritage sites in Wuhan from subsidence and urban sprawl
  - Detection of looting activities –possibly carrying on in Dragon-6
  - Earthquake damage detection to cultural heritage in Turkey
- Reschedule fieldwork activities in China and Europa, focusing on accessible sites

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