



2022 DRAGON 5 SYMPOSIUM

MID-TERM RESULTS REPORTING

17-21 OCTOBER 2022

PROJECT ID. 58113

**SARchaeology: EXPLOITING SATELLITE SAR
FOR ARCHAEOLOGICAL PROSPECTION AND
HERITAGE SITE PROTECTION**

DAY 5 - 21 OCT 2022



THE UNIVERSITY OF
SYDNEY



中国科学院
CHINESE ACADEMY OF SCIENCES



ID. 58113

PROJECT TITLE: SARchaeology: exploiting satellite SAR for archaeological prospection and heritage site protection

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PRESENTED BY: Dr. Francesca Cigna [PI Europe]

- 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 centres, natural reserves, paleo-channels and ice patches with organic remains
- Through a range of case study sites in China, Russia, Mongolia, Italy, Norway and Bulgaria



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”

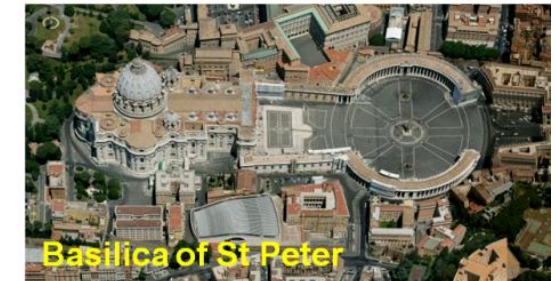
ESA Third Party Missions	No. Scenes
1. TerraSAR-X (ftp)	6
2. RADARSAT-1/2 (ftp)	6
3. DEIMOS-2 (ftp)	160 km ²
4. WorldView/GeoEye/QuickBird (ftp)	40 km ²
5. Pléiades-1, RapidEye-1/5, IKONOS-2, Kompsat-2, WV-2 (ESA Collections)	27
6. TerraSAR-X (external licenses)	160
7. COSMO-SkyMed (external licenses)	410
Total:	609 scenes + 200 km ²
Issues: n/a	

ESA, Explorers & Sentinels data	No. Scenes
1. Sentinel-1	575
2. Sentinel-2	32
3. ERS-1/2	34
4. ENVISAT	33
5.	
6.	
Total:	674 scenes
Issues: n/a	

Chinese EO data	No. Scenes
1. Jilin-1 (<i>data request submitted</i>)	0
2. CBERS-4	0
3.	
4.	
5.	
6.	
Total:	0
Issues: CBERS-4 image catalogue only accessible to Chinese users; though INPE's catalogue suggests that no CBERS-4 data is available for some of the project AOIs	

- **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
- **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 imagery for urban development and induced risk for heritage
 - 5) Tuva Republic: improving methodologies and monitoring burial mounds
 - 6) Wuhan: simulation of looting pits and analysis of their detectability in high-resolution SAR imagery
 - 7) Jiuzhaigou, Sichuan: post-disaster monitoring of the UNESCO natural heritage site

- **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 and achievements:**

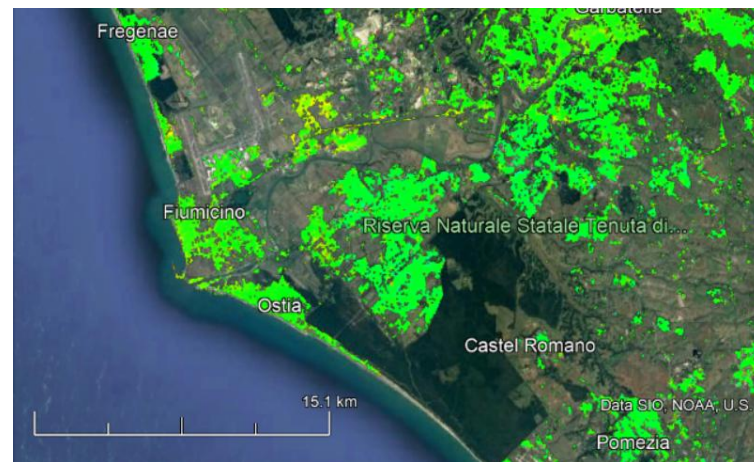
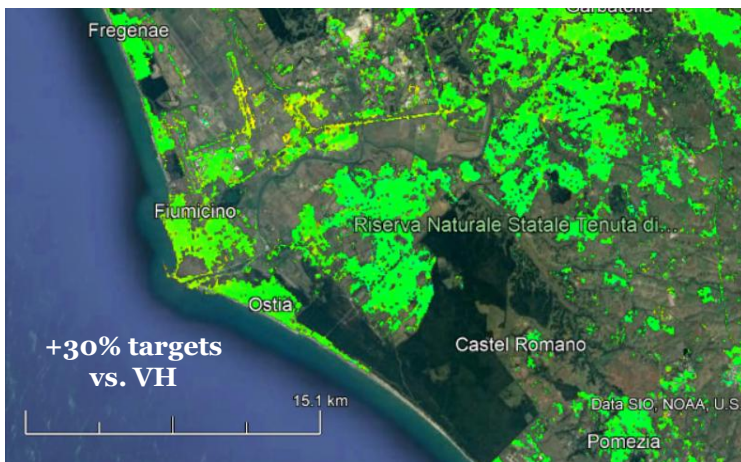
- Estimation of 2018-2022 ground displacement rates and time series for coherent targets across Latium Region (17,242 km²)
- Identification of hotspots showing significant land deformation (subsidence), some involving monuments and heritage assets
- Comparison of the performances of SBAS InSAR processing of VV and VH channels (at equal conditions, no. of scenes, thresholds)

LOS displacement rates in Aug 2019 – Jul 2021

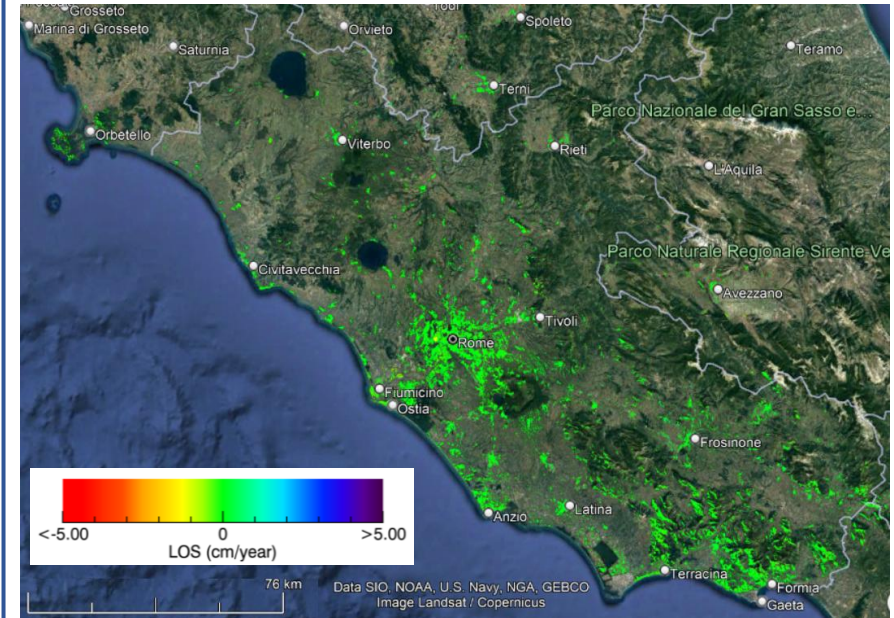
106 S1A/B scenes, T117 ascending

VV channel (~456,000 targets)

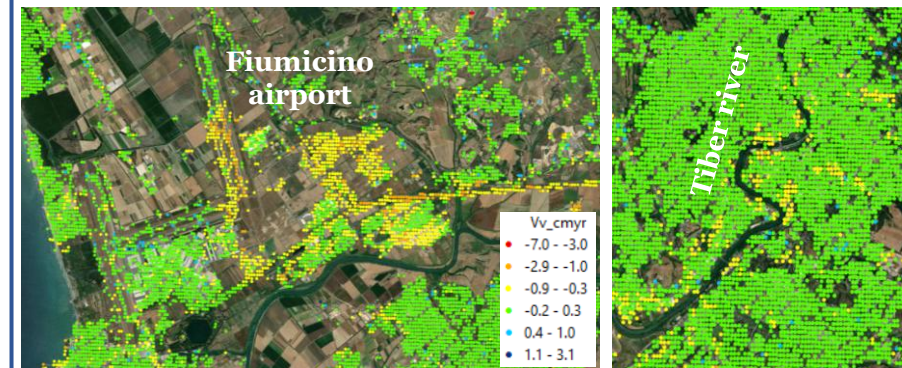
VH channel (~350,000 targets)



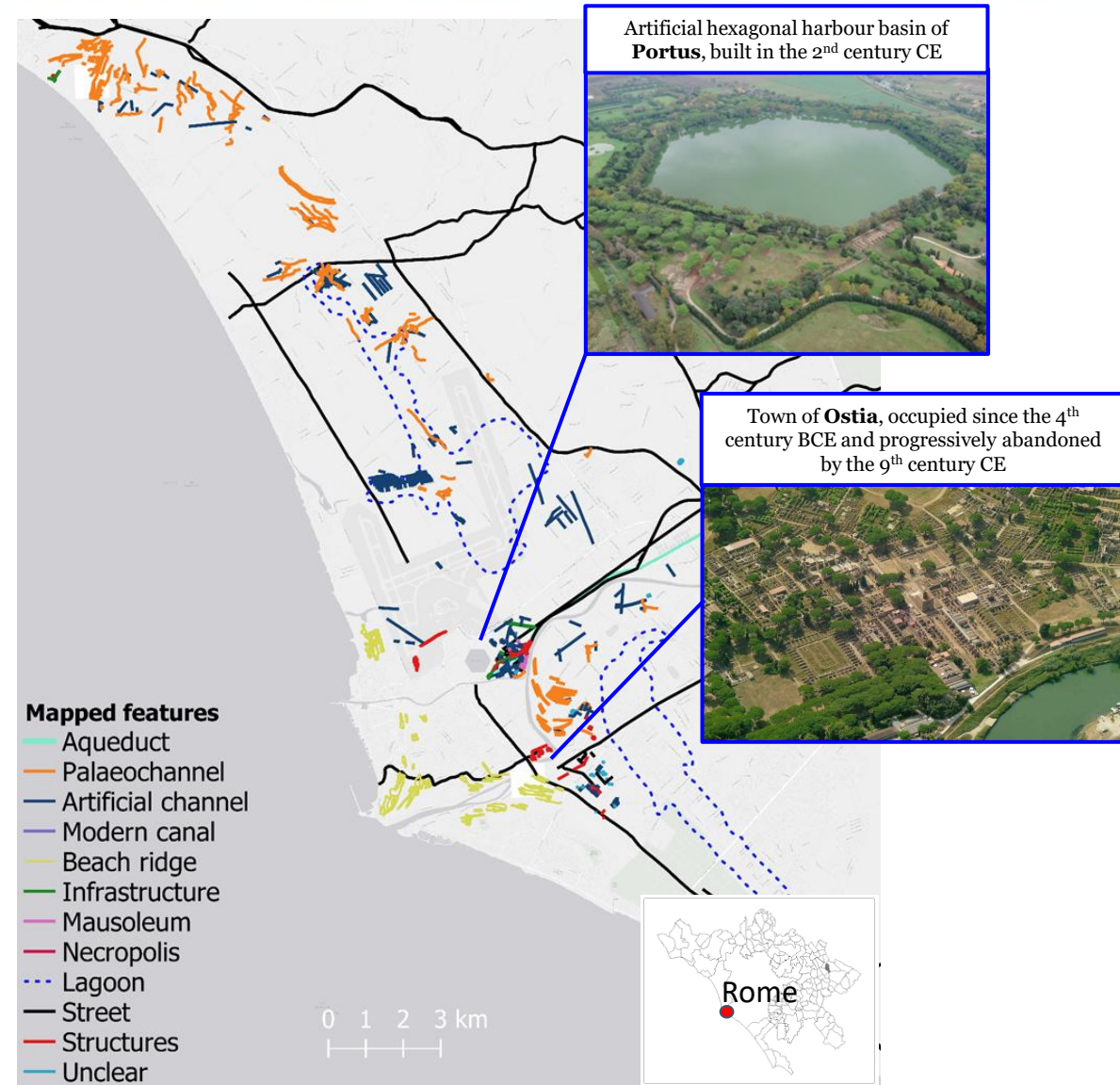
LOS displacement rates in Jan 2018 – Feb 2022
124 S1A scenes, T117 ascending, >460,700 coherent targets



Ground instability hotspots



- **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
- **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
- **In-situ data:** vegetation status, ploughing/harvesting activity, crop/soil marks visibility



- Key results and achievements:**

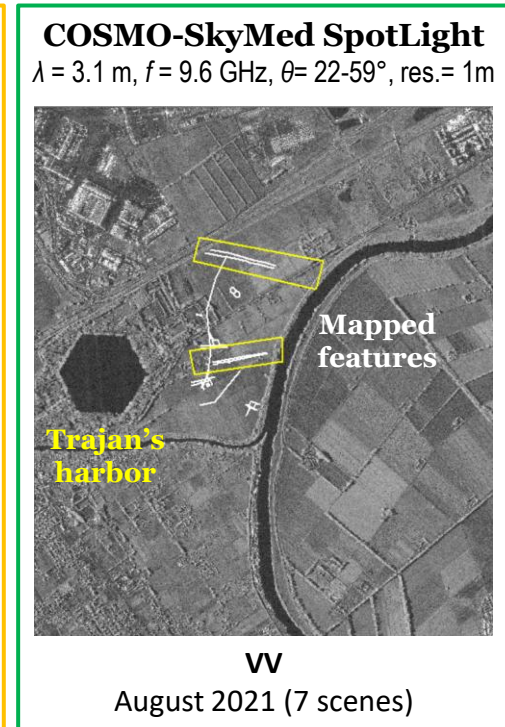
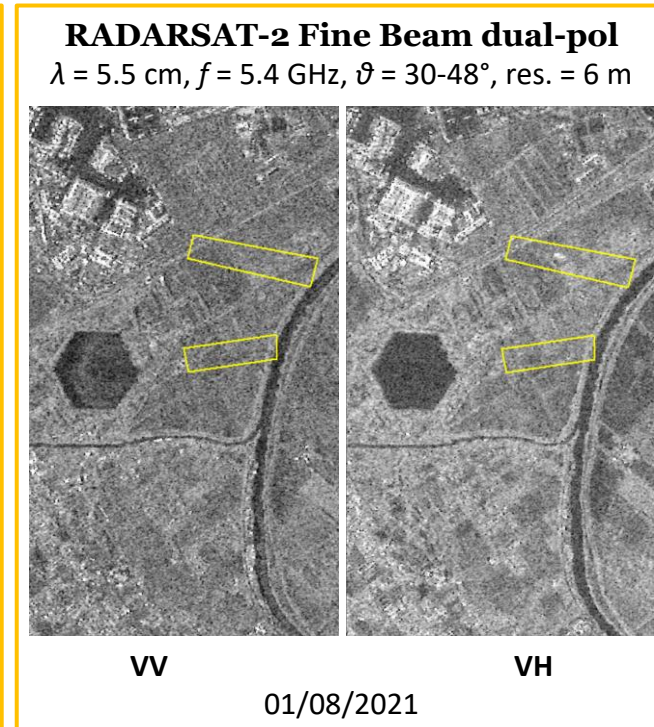
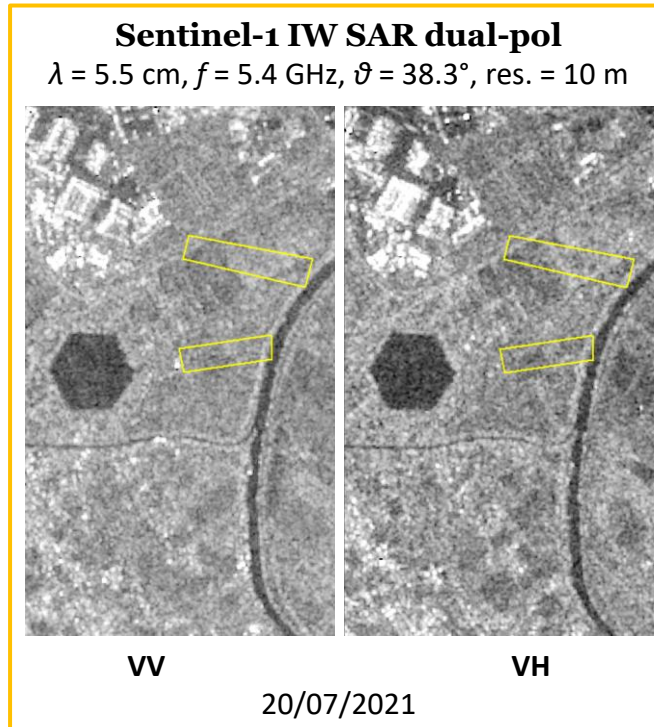
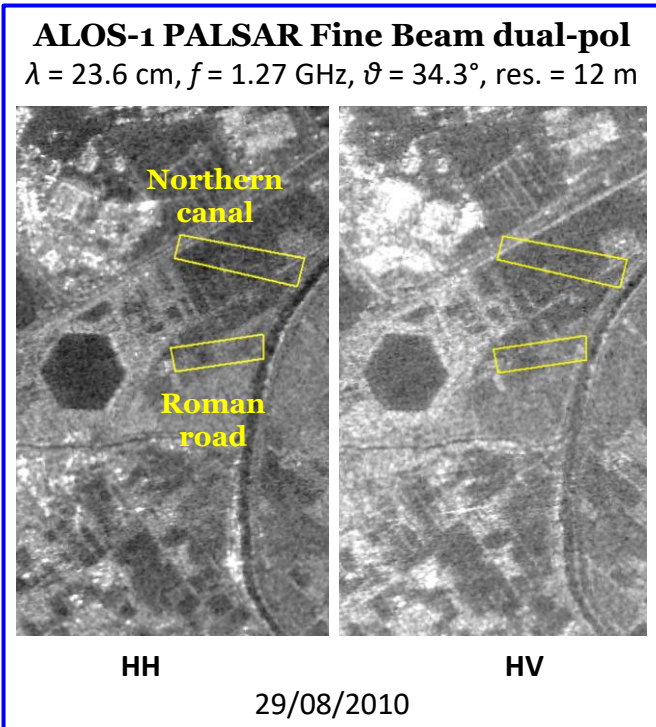
- Identification of differences in crop marks detectability at the different polarisations (HH, HV, VV, VH), resolutions (12 to 1 m) and bands (L, C, X)
- SAR image interpretation, aided by VHR optical data and validated by field evidence

see also European YS' poster ID 120

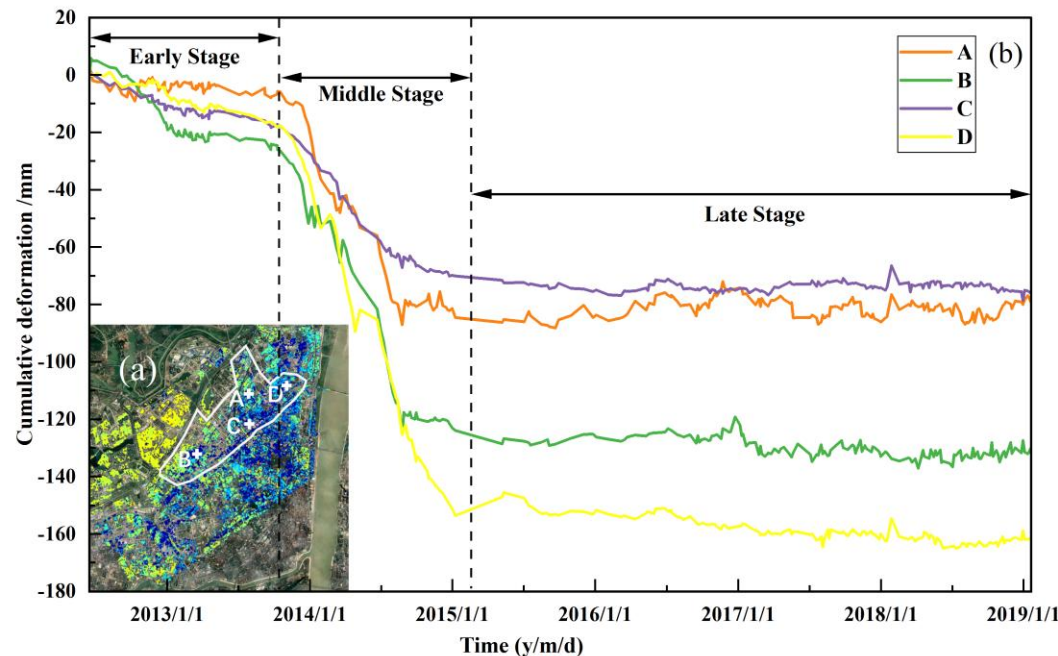
L-band

C-band

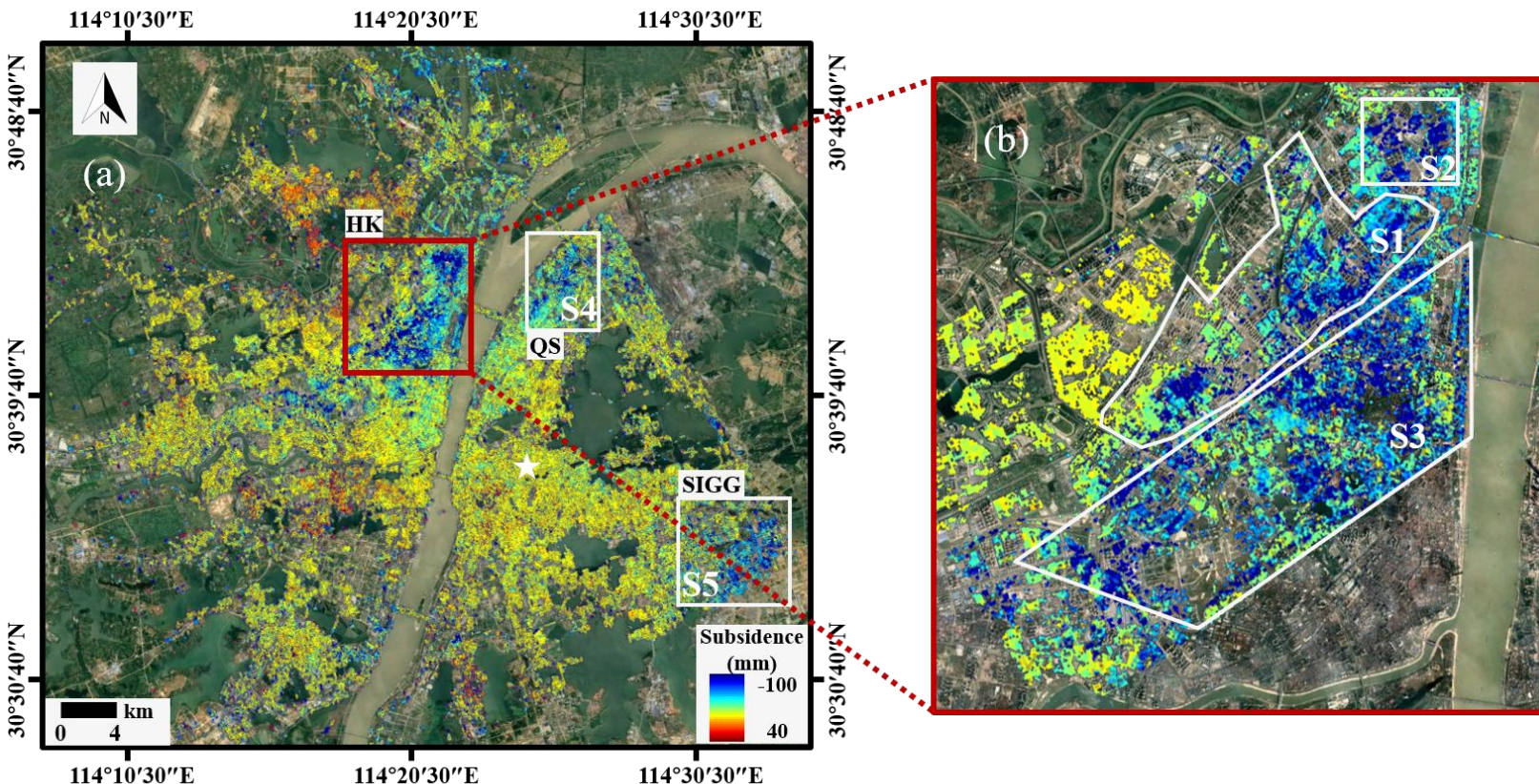
X-band



- **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:** X-band COSMO-SkyMed and TerraSAR-X StripMap data
- **Method:** non-linear PSInSAR and data fusion using PEKM and LSTM
- **In-situ data:** long-term GNSS measurement



- **Key results and achievements:**
 - Long-term monitoring of surface deformation
 - Non-linear deformation estimation
 - Published in and cover of *Remote Sensing*



remote sensing

IMPACT FACTOR 4.509

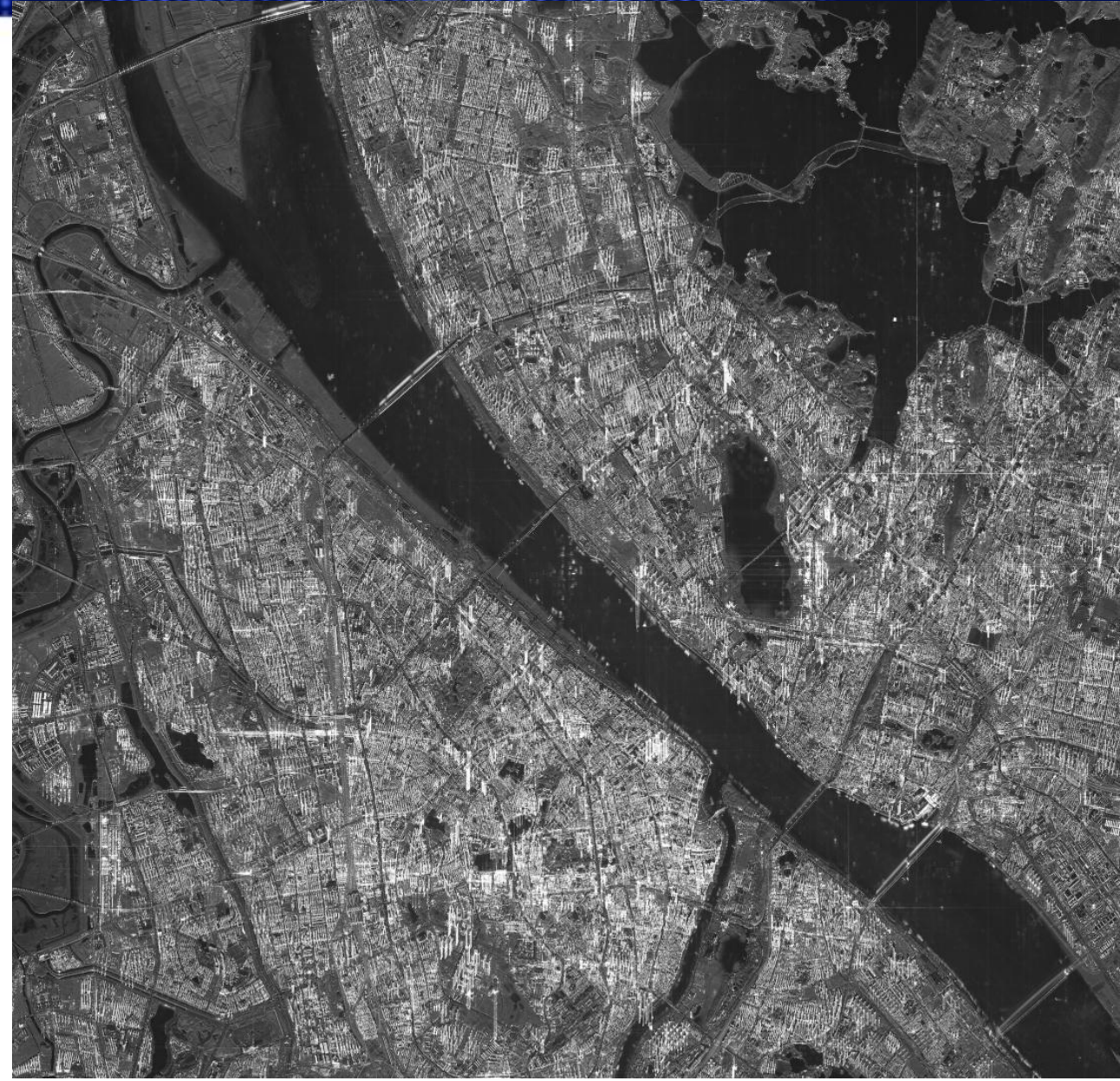
CITESCORE 6.1 SCOPUS

Land Subsidence in Wuhan Revealed Using a Non-Linear PSInSAR Approach with Long Time Series of COSMO-SkyMed SAR Data

Volume 13 · Issue 7 | April (I) 2021

MDPI | [mdpi.com/journal/remotesensing](https://www.mdpi.com/journal/remotesensing)
ISSN 2072-4292

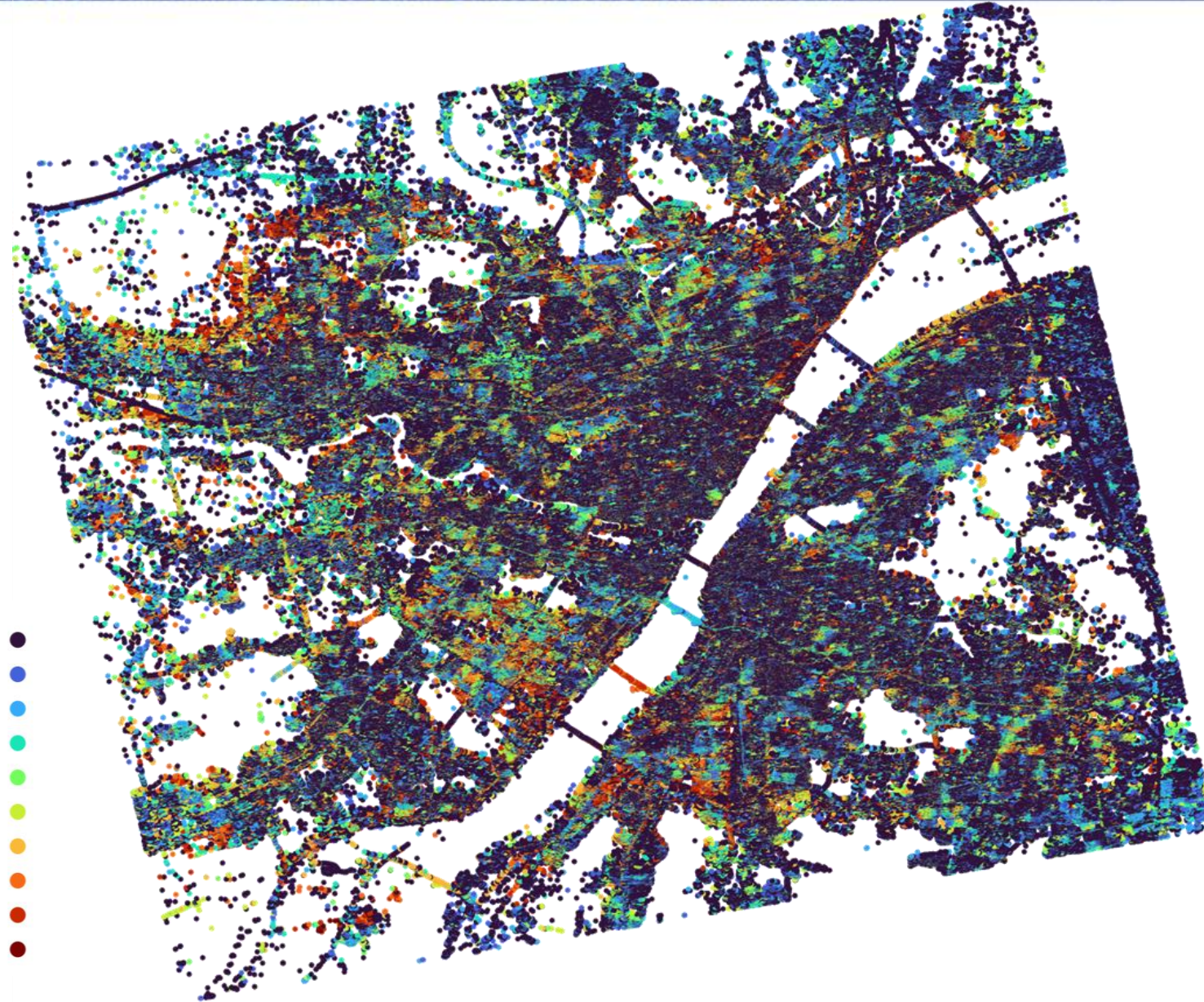
- **Type of heritage:** mostly colonial era buildings, World War heritage from the battle of Wuhan and Mao era heritage
- **Scientific goal:** monitoring the urban development in Wuhan, especially the vertical development with multi-baseline InSAR
- **EO data used:** X-band COSMO-SkyMed and TerraSAR-X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



- **Key results and achievements:**

- Identification of urban development using the dynamic identification of temporal PS
- Analysis of development axes in Wuhan
- Quantifying inner-urban densification that endangers heritage sites
- Vertical development of Wuhan over time

< 2012 ●
 2012 ●
 2013 ●
 2014 ●
 2015 ●
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 2017 ●
 2018 ●
 2019 ●
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- **Type of heritage:** burial mounds
- **Scientific goal:** to support detection and archaeological prospection of burial mounds
- **EO data used:** C-band Sentinel-1 data 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



- **Type of heritage:** looting indicators
- **Scientific goal:** to determine detectability of looting sites in SAR data
- **EO data used:** X-band TerraSAR-X high resolution & StripMap data
- **Method:** image interpretation, machine learning, coherence change detection
- **In-situ data:** field experiment



- **Key results and achievements:**

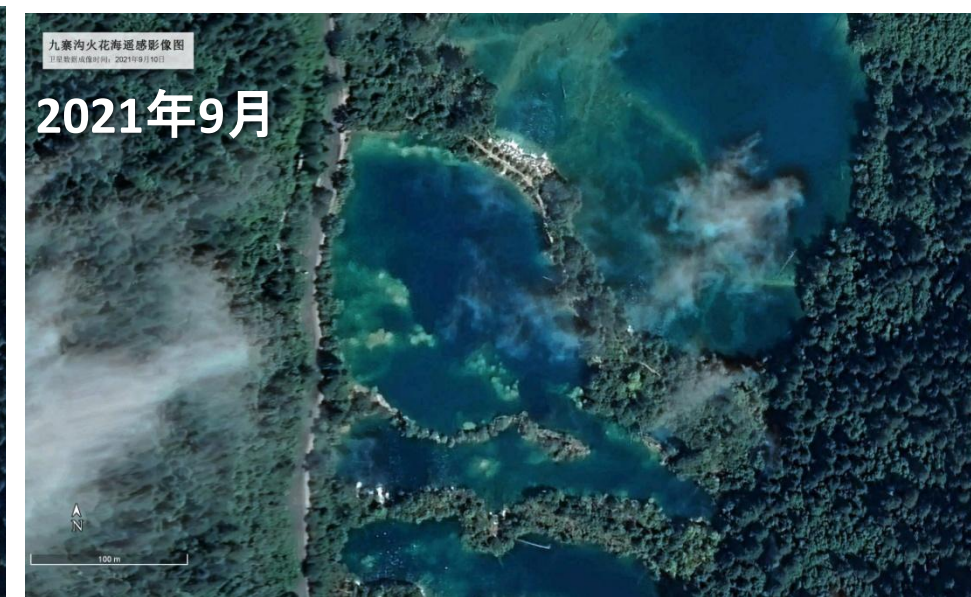
- First image acquired
- Experiment location defined
- Experiment delayed to early 2023, due to constraints in image acquisition



- **Type of heritage:** Jiuzhaigou UNESCO natural heritage sites
- **Scientific goal:** post-disaster monitoring in extreme area and support of conservation efforts
- **EO data used:** multi-source RS data and UAV
- **Method:** image interpretation, change detection, machine learning
- **In-situ data:** field work and cooperation with heritage site administration



- **Key results and achievements:**
 - Multi-source monitoring of the post-disaster situation
 - High-resolution UAV deployment
 - Supporting the conservation efforts at Jiuzhaigou UNESCO heritage site



Name	Institution	Poster title	Contribution
Mr. Michele Abballe	CNR-ISAC	Archaeological mapping through optical and SAR imagery in the hinterlands of Ostia and Portus (Italy)	ID. 120

- Level and training:

- 1 year-long postgraduate research fellowship at CNR-ISAC [Apr 2022 – Mar 2023]
- PhD candidate in Archaeology at Ghent University, Belgium [viva planned; end 2022 / early 2023]
- On-the-job training 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]

- Publication and dissemination activities:

- 1 first-authored oral presentation at Landscape Archaeology Conference (LAC 2022), 10-15 Sept 2022
- Will contribute to the Dragon-5 Mid-Term project conference proceeding/paper in 2022

Name	Institution	Poster title	Contribution
Mr. Haonan Jiang	LIESMARS, Wuhan University	-	ID. 118 (embedded into this PPT)

- Level and training:

- PhD student in Photogrammetry and Remote Sensing at LIESMARS, Wuhan University [since 2019]

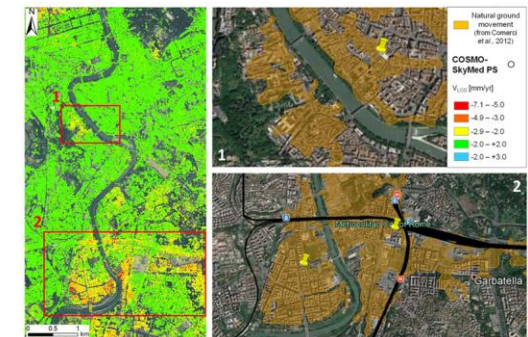
- Publication and dissemination activities:

- 1 first-authored article on COSMO-SkyMed monitoring of land subsidence in Wuhan, published as 'Feature Paper' in the international journal *Remote Sensing* in 2021 (<https://doi.org/10.3390/rs13071256>)
- 1 co-authored conference proceeding at IEEE IGARSS 2021 (<https://doi.org/10.1109/IGARSS47720.2021.9554360>)
- 1 first-authored article on InSAR time series data fusion, recently submitted to top-ranked international journal
- Will contribute to the Dragon-5 Mid-Term project conference proceeding/paper in 2022

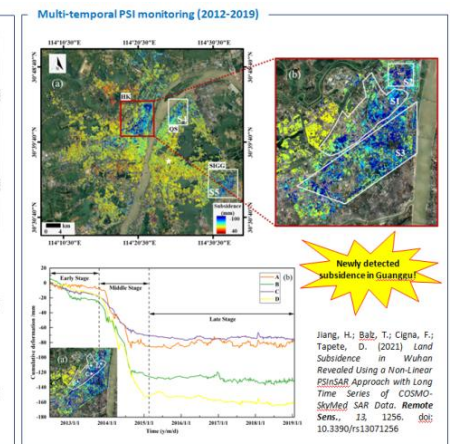
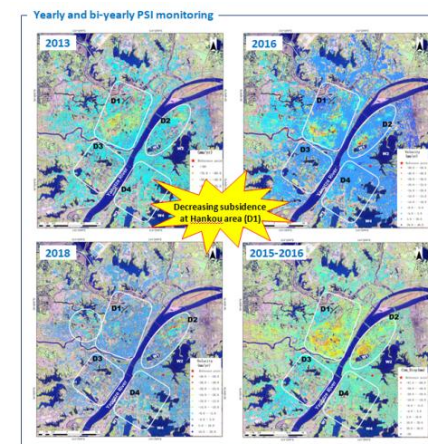
Prof. Timo Balz led the ***Microwave Remote Sensing Course*** at Wuhan University in mid 2020, and Dr. Deodato Tapete and Dr. Gino Caspari gave online lectures on SAR applications for archaeology



Prof. Bihong Fu organized the ***International Workshop on Space Technologies for Disaster Mitigation of World Heritage*** in Jiuzhaigou, China on 13-16 Oct 2020, 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

Jiang, H.; Bai, T.; Cigna, F.; Tapete, D. (2021) Land Subsidence in Wuhan Revealed Using a Non-Linear PSInSAR Approach with Long Time Series of COSMO-SkyMed SAR Data. Remote Sens., 13, 1256. doi: 10.3390/rs13071256

The team 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 (e.g. AIR-CAS' Key Laboratory of Digital Earth Science; UNESCO's Int. Centre on Space Technologies for Natural and Cultural Heritage, HIST; CNR's Institute of Heritage Science, CNR-ISPC):



- 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 = 23.178; Q1 in Multidisciplinary Sciences]
- CHEN F., LIU H., XU H., ZHOU W., BALZ T., CHEN P., ZHU X., LIN H., FANG C., PARCHARIDIS I. 2021. Deformation monitoring and thematic mapping of the Badaling Great Wall using very high-resolution interferometric synthetic aperture radar data. *Int. J. of Applied Earth Observation and Geoinformation*, 105, 102630, <https://doi.org/10.1016/j.jag.2021.102630> [IF = 7.672; Q1 in Remote Sensing]
- CHEN F., GUO H., TAPETE D., CIGNA F., PIRO S., LASAPONARA R., MASINI N. 2022. The role of imaging radar in cultural heritage: from technologies to applications. *Int. J. of Applied Earth Observation and Geoinformation*, 112, 102907, <https://doi.org/10.1016/j.jag.2022.102907> [Review paper] [IF = 7.672; Q1 in Remote Sensing]
- CHEN F., ZHOU W., TANG Y., LI R., LIN H., BALZ T., LUO J., SHI P., ZHU M., FANG C. 2022. Remote sensing-based deformation monitoring of pagodas at the Bagan cultural heritage site, Myanmar. *Int. J. of Digital Earth*, 15 (1), 770-788, <https://doi.org/10.1080/17538947.2022.2062466> [IF = 7.672; Q1 in Remote Sensing]

- Further develop and finalize the ongoing research activities in the Province of Rome, the city of Wuhan and Tuva, and prepare manuscripts for submission to scientific journals in 2023
- Identify other training and academic exchange opportunities for the Chinese and European Ys to further develop their EO data analysis skills
- Enroll more Chinese and European Ys through MSc, BSc and other postgraduate programs, to carry out their thesis/internship projects linking with one or more of the key scientific goals of SARchaeology
- Resume and/or kick off research activities on:
 - UNESCO natural heritage in Jiuzhaigou (China) to detect ground instability, land cover changes and impacts of tourism
 - Lop-Nor (China) to detect palaeo-channels and reconstruct the palaeo-environment
 - Taklamakan desert, Xinjiang (China) to study Bronze Age cemeteries and other structures across the desert
 - Altai and Tianshan, Xinjiang (China) to detect Iron Age burial mounds (kurgans)
 - Bulgaria, to investigate Thracian burial mounds and monitor looting through InSAR coherence
- Reschedule fieldwork activities in the Khanuy Valley and ice patches (Mongolia) and the Valley of the Kings, Uyuk Valley, Tuva Republic (Russia), currently on hold due to COVID-19 travel restrictions and Russian-Ukrainian conflict, respectively