ERA4CH

D1.3 Analysis of remote sensing methods and data

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1. INTRODUCTION

1.1 Project Abstract

The ERA4CH (Earthquake Risk plAtform For european cities Cultural Heritage protection) project addresses the development of a series of tools, combining Artificial Intelligence with structural stability models, advanced remote sensing techniques, image processing, geotechnics and cadastral data sets in a GIS application for damage assessment and long-term monitoring of historic centres. This innovative methodology and tools will enable effective monitoring and management of the historic centres to mitigate the effects of catastrophic events by enabling preventive intervention in the areas where the majority of the damage is expected. In order to carry out the demonstration and validation of the Platform, three case studies have been selected: the Italian site of the city centre of Narni (UNESCO site), the Chania historical city in Greece and Strovolos city in Cyprus case studies. The project is outlined on the web page https://era4ch.eu/home/.

1.2 Document scope

This document is the **deliverable D1.3 Analysis of remote sensing methods and data.** Its intended use is to analyse Remote Sensing (RS) (satellite, aerial, terrestrial) methods and data according to the related to **Task T1.3**. The general goal of this document is to define, specify, and thoroughly examine the most promising RS (satellite, aerial, and terrestrial) approaches that will be used in the project. In addition to mapping, change detection, and data needed for particular applications, these approaches will cover a variety of data helpful for the Cultural Heritage (CH) risk assessment of structural stability.

The overall aim of this activity is twofold: (i) to identify, define and analyse in detail the most promising RS methods that will be implemented within the framework of ERA4CH and (ii) to define the data (satellite, aerial, terrestrial) that will be required for continuous monitoring of the risk of the CH.

1.3 Applicable Documents

Ref	Document-ID	Document title	Issue
[A1]	GA-101086280	Grant Agreement number: 101086280 — ERA4CH — HORIZON-MSCA-2021-SE-01	01/01/2023
[A2]	N/A	Consortium Agreement	Issue 1.1 date 01/01/2023

Table 1 – Applicable documents

1.4 Reference Documents

	Document-ID	Document title	Issue
[R1]	ECSS	European Cooperation for Space Standardization document series	latest

Table 2 – Reference documents

1.5 Definition & Acronyms

Acronym	Description
A-DInSAR	Advanced Differential SAR interferometry
ALS	Aerial Laser Scanning
CH	Cultural Heritage
CNN	Convolutional Neural Network
DEM	Digital Elevation Model
DinSAR	Differential Interferometry Synthetic Aperture Radar
DSM	Digital Surface Model
DTM	Digital Terrain Model
EO	Earth Observation
GPR	Ground Penetrating Radar
hDEMs	historical Digital Elevation Models
InSAR	Synthetic Aperture Radar Interferometry
LiDAR	Light Detection and Ranging
ML	Machine Learning
NIR	Near-Infrared
PSI	Persistent Scatterer Interferometry
PS-InSAR	Persistent Scatterer Interferometry
PS	Persistent Scatterers
RS	Remote Sensing
SAR	Synthetic Aperture Radar
SDG	Sustainable Development Goals
SBAS-InSAR	Small Baseline Subset InSAR
SNAP	Sentinel Application Platform
SWIR	Shortwave Infrared
TLS	Terrestrial Laser Scanning
UAV	Unnamed Aerial Vehicles

Acronym	Description
UN	United Nations
VHR	Very High Resolution

Table 3 – Definitions & acronyms

2. GENERAL MONITORING SYSTEMS

The structural stability of the CH, which is frequently characterized by old construction techniques and materials, is greatly influenced by the Earth's seismic activity.

By assisting disaster managers and specialists in creating mitigation measures, prioritizing investments in resilient cultural property, and decreasing economic losses, risk information becomes essential to lowering the vulnerability of heritage and minimizing economic losses. The **goal of the ERA4CH project** is to create a set of tools for damage assessment and long-term monitoring of historic centers that integrate artificial intelligence with structural stability models, cutting-edge remote sensing methods, image processing, geotechnics, and cadastral data sets.

Remote sensing is a term used to refer to any CH monitoring methods that employ non-direct touch equipment to view objects of interest on the Earth's (sub)surface from the ground or above. Even though some academics and experts refer to these as ground-based or underwater remote sensing, this definition includes geophysical methods (such as Ground Penetrating Radar (GPR), electrical resistivity tomography, and electromagnetic methods) and acoustic methods (such as sound navigation and ranging). Airborne and spaceborne remote sensing techniques are the most widely used tools for CH purposes (Luo et al., 2019).

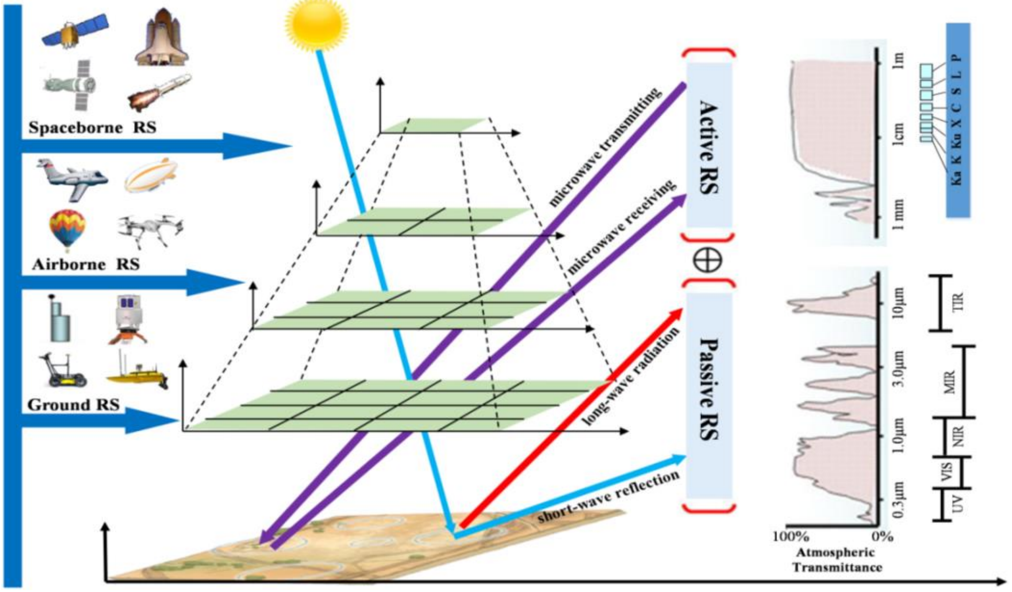

Figure 2-1 The remote sensing (RS) schematic for ACH applications (Luo et al., 2019).

The state-of-the-art and scientific basis of the monitoring techniques utilized in the ERA4CH project are discussed in this chapter. In particular, "Remote sensing methods" in paragraph 2.2 will introduce (i) satellite Synthetic Aperture Radar interferometry (SAR), with a general introduction and a description of advanced differential SAR interferometry (A-DInSAR) and the Persistent Scatterer Interferometry (PSI). Many works and studies have shown a huge potential for geo-hazards monitoring by using a wide range of spatial scales (regional to local), temporal samplings (yearly to days), and significantly high precisions (up to a few millimetres). As a result, the study of landslide risk with satellite remote sensors (e.g., DInSAR analysis) now relies on some decades of solids applications. With the help of satellite monitoring, the position, activity, size, severity, and magnitude of landslides can now be quickly identified.

2.1 Policy Framework for the Application of Earth Observation (EO) towards safeguarding CH

The preservation of archaeological and CH is a strategic priority helping the UN achieve its 2030 Sustainable Development Goals (SDGs) and ensuring that valuable assets from the past are preserved and passed on to future generations (Luo et al., 2019).

CH is a catalyst and facilitator for the sustainable development of society and is one of the primary holders of cultural variety on the planet ("19th General Assembly 2017 - International Council on Monuments and Sites," n.d.). To quickly offer monitoring and management methods against damage and the loss of cultural variety, it is essential to find, document, and comprehend CH sites and their changes across time and place (Vaz et al., 2019). The UN's Sustainable Development Goals (SDGs) specifically address this, with Goal 11.4 stating that we must "increase efforts to protect and safeguard the world's cultural and natural heritage in order to make our cities inclusive, safe, resilient, and sustainable"("Goal 11 | Department of Economic and Social Affairs," n.d.).

However, the fundamental basis for CH management and monitoring is field observations connected to physical surveys, taking into account various geographic locations, and using appropriate in situ analytical techniques. Such a technique is time- and money-consuming as it usually does not allow for temporal repeats. As a result, it became urgently necessary to create new, inexpensive techniques and stakeholder networks to address the aforementioned problems at multiple levels (Luo et al., 2019).

2.2 Differential SAR interferometry (A-DInSAR) and the Persistent Scatterer Interferometry (PSI)

Land movement is one of the most severe types of natural disasters that could endanger people and public property such as archaeological sites. The use of SAR technology has been widely used for detecting land subsidence after earthquakes or landslides. Nowadays, due to technology advancements, there are many missions (such as COSMO-SkyMed[1] and ERS-1/2[2]), and a variety of satellite data that is openly accessible to everyone, for instance, the Sentinel-1[3] mission. With the help of satellite monitoring, the position, activity, size, severity, and magnitude of landslides can now be quickly identified. Particularly, the focus will be on subsidence and landslide risks and their impact on the structural stability of the CH (Macchiarulo et al., 2023).

2.2.1 Synthetic Aperture Radar (SAR)

Synthetic Aperture Radar (SAR) is a type of active data gathering in which a sensor generates its energy and then measures the percentage of the back-scattered energy after interacting with the ground. SAR data requires an entirely different approach since the signal is susceptible to surface properties such as structure and wetness. The spatial resolution of radar data is directly related to the ratio of the sensor wavelength to the length of the sensor's antenna.

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[1] https://earth.esa.int/eogateway/missions/cosmo-skymed#data-section

[2] https://earth.esa.int/eogateway/missions/ers/data

[3] https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-1

A satellite SAR image is made up of a matrix of pixels grouped along the azimuth (parallel to the satellite's movement) and slant range (orthogonal with respect to the flight direction) directions. Each pixel stores information regarding the amplitude and phase of the signal reflected by the detected objects. The amplitude of the signal reflected to the sensor denotes its energy, whereas the phase indicates the distance between the sensor and the backscattering target on the ground.

Radar sensors have the advantage of precisely regulating signal polarisation on both transmit and receive. Signals emitted in vertical (V) polarisation and received in horizontal (H) polarisation are denoted by a VH. Alternatively, HH would represent a signal that was emitted in horizontal (H) and received in horizontal (H), and so on.

The signal strength from these multiple polarisations carries information about the structure of the imaged surface, based on the scattering types' rough surface, volume, and double bounce.

- VV scattering is especially sensitive to rough surface scattering, such as that induced by bare soil or water.
- Volume scattering, such as that induced by leaves and branches in a forest canopy, is particularly sensitive to cross-polarized data such as VH or HV.
- The final type of dispersion is double bounce, which is induced by buildings, tree trunks, or flooded vegetation and is particularly sensitive to an HH polarised signal (Earth Science Data Systems, 2020).

SAR is more effective than optical imaging with a low solar elevation angle for finding buried features, soil marks, and micro- and medium-relief for archaeological applications (Luo et al., 2019).

They can be used to evaluate the degree and extent of earthquake-related damage to CH assets. Structures, monuments, and landscape changes can be recognized and measured by comparing pre- and post-event SAR data. The capacity of SAR to detect ground displacements aids in identifying potential seismic event-induced subsidence, settlement, or uplift of cultural heritage sites. Areas that are more likely to sustain damage from earthquakes can be identified by analyzing SAR data. The most endangered CH sites can be protected by concentrating resources and conservation efforts on them. This can help authorities and conservation groups coordinate emergency response strategies and launch preservation efforts (Earth Science Data Systems, 2020).

SAR operates independently of weather conditions, lighting and the time of the day making it suitable for archaeological surveys in regions with frequent cloud cover, rain, or low-light conditions.

As a result, it can be argued that SAR images are a well-suited and advantageous satellite-derived resource for monitoring and tracking CH sites that have been damaged or destroyed. Furthermore, the variety and depth of SAR imagery in characterizing the degree of damage incurred by CH sites are notable. The high-resolution nature of SAR images allows for a thorough examination of structural flaws. This in-depth assessment not only aids in determining the size and severity of the damage, allowing for effective resource allocation for restoration efforts, but it also enables professionals to distinguish between partial and complete destruction, assisting in strategic decision-making processes.

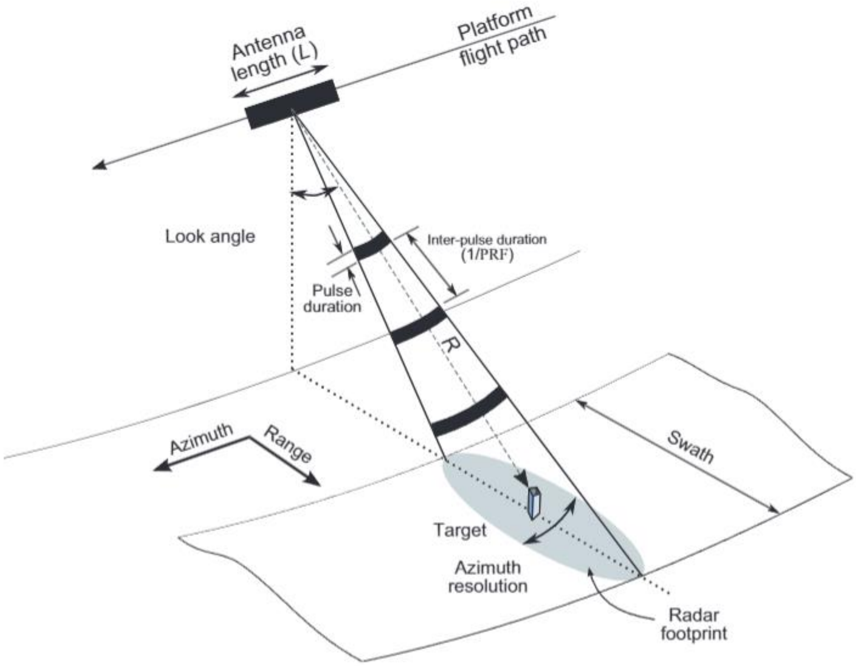

Figure 2-2 Radar imaging system geometry (Bouaraba et al., 2018)

2.2.2 Differential Interferometry Synthetic Aperture Radar (DInSAR)

SAR technology, which gathers pictures of the Earth's surface, is the foundation for radar satellite imaging. SAR sensors use microwave radiation to pass through clouds, foliage, and other obstructions, in contrast to optical sensors, which depend on visible and near-infrared light, to collect data under a variety of environmental conditions. The primary satellite remote sensing method for determining changes in the Earth's surface is InSAR (Synthetic Aperture Radar Interferometry) (Hanssen, 2001; Massonnet and Feigl, 1998). A remote sensing method called Differential Interferometry Synthetic Aperture Radar (**DInSAR)** is used to quantify and keep track of terrain deformations. It is composed of comparing the interferometric phase of two or more SAR images that were taken over the same region at different times (“User Guides - Sentinel-1 SAR - Interferometry - Sentinel Online,” n.d.).

Information about the phase difference is derived from the Interferogram which represents the basic element of this methodology. In particular, the phase of each pixel is given by the sum of two terms:

$$\varphi = \varphi_s + \varphi_r \quad (1)$$

The first (φ_s) is related to the scatterers within the scene; the second (φ_r) depends on the double path satellite target and on the wavelength of the electromagnetic pulse emitted and then recorded by the sensor:

$$\varphi_r = \frac{4 * \pi * r}{\lambda} (2)$$

r is the distance between the satellite and the target on the ground along the range direction and is the wavelength. However, the phase of a single SAR image cannot be used because:

• φ_s is random;

• φ_r depends on r, that is in the order of hundreds of kilometers and on λ that, on the contrary, is in the order of a few centimeters.

In fact, the electromagnetic wave, for each pixel, is sent from the SAR antenna to the Earth's surface; during the satellite-ground path, the sinusoidal signal performs millions of cycles, hits the targets with a particular phase value and is randomly backscattered (multiple reflections, φ_s). Finally, part of the signal returns to the satellite, which records the information.

By considering the phase difference between two SAR images, of the same target is deleted and the interferometric phase Δφ and the interferometric phase is given by:

$$\Delta\varphi = \frac{4 * \pi * DR}{\lambda} \quad (3)$$

Δφ is characterized by the following main contributions:

$$\Delta\varphi = \Delta\varphi_f + \Delta\varphi_{topo} + \Delta\varphi_{displ} + \Delta\varphi_{atm} + \Delta\varphi_{err} \text{ (4)}$$

- $\Delta\varphi_f$ is called "flat Earth phase" and is due to the different angles of view of the satellites during the acquisition of the image. It is a contribution easy to remove.
- $\Delta\varphi_{topo}$ is the phase component containing the topographical information, that is the relation between phase and height. This phase contribution can be estimated by using a DEM (Digital Elevation Model).
- $\Delta\varphi_{atm}$ represents a random element caused by the different weather conditions during the acquisition of SAR images over time.
- $\Delta\varphi_{displ}$ is the contribution to the interferometric phase due to the Earth's surface displacements.
- $\Delta\varphi_{err}$ is a residual noise not directly determinable.

Equation (4) gives the differential interferogram. A DEM (Digital Elevation Model) can readily eliminate the flat Earth contribution and topographic phase, as well as a reference ellipsoid. So, in order to identify displacement information, $\Delta\varphi_{atm}$ and $\Delta\varphi_{err}$ must be approximated, allowing the phase component associated with displacement to be retrieved.

The key idea of Multi-Image InSAR or Advanced DInSAR methods (A-DInSAR) is the combination of information from a large number of SAR images, allowing the temporal development of displacements of objects on the ground during the time of interest to be calculated. The quantity of photos available for such analysis determines the quality of the results. A-DInSAR approaches may identify and estimate the progression of deformation processes in the past (historical analysis) and/or in the present.

2.2.2.1 Workflow of the DInSAR method

The Sentinel Application Platform (SNAP) software[4], is an open-source software that is provided by the European Space Agency ("SNAP Download – STEP," n.d.). SNAP has toolboxes for all data types. This application can process, analyze, and observe the Earth in five main pillars: sea, land, atmosphere, safety and emergencies.

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[4] https://step.esa.int/main/download/snap-download/

The four primary components of the methodological framework are shown below (Figure 2-3). The suitability of the data is verified before they are chosen, downloaded, and entered into the software, consisting of the first component. The nature of the data is more thoroughly described in the next section (section 3).

The second section covers tools like Split, Apply-Orbit file, Back-Geocoding, Enhanced Spectral Diversity, Interferogram creation, and TOPSAR Deburst that are used during the pre-processing stages of InSAR Interferometry. Specifically, image preprocessing includes atmospheric and radiometric adjustments, as well as geometric correction to align the images in terms of their spatial coordinates. Regarding the interferogram generation, it requires computing the phase difference between the images, by subtracting the phase of the reference image from the phase of the secondary image.

The D-InSAR interferometry proceedings are included in the third part. These utilities are Snaphu Export, Multilook, and Goldstein Filtering. One of the most crucial steps of this component is phase unwrapping, since initial phase values are wrapped within a limited range, due to the periodic nature of phase measurements. The aim is to obtain the actual phase difference values and a continuous representation of the phase difference. At the same time, it is essential to remove the topographic phase component from the observed phase, since changes in topography may lead to variations in the observed phase that are not necessarily related to deformation.

The fourth and final section (section 4 - Final Result Velocity Maps) is the primary processing stage, where the land motions are identified and mapped. The resulting phase values in the interferogram represent the differential ground displacement between the two acquisition times of the SAR images, which provide insight into the magnitude and direction of ground deformation. Once the deformation maps are generated, they can be compared to identify patterns and changes in deformation rates.

This methodology needs to be followed before and after serious seismic activity, which can potentially damage CH and archaeological sites. Surface deformation analysis is critical in CH for monitoring and indicates possible damaged areas (Tayeb et al., 2022).

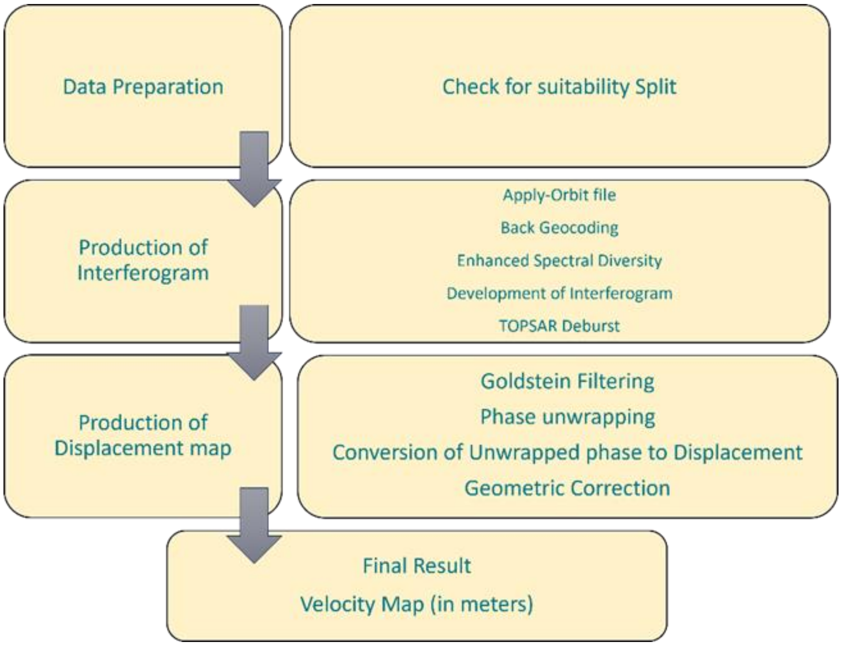

Figure 2-3 The methodological framework

2.2.3 Persistent Scatterer Interferometry (PSI)

In order to determine a single coherent pixel's displacement velocity within a huge collection of SAR data, the PS-InSAR (Persistent Scatterer Interferometry) technique suggests identifying Persistent Scatterers (PSs), which are single coherent pixels (Moise et al., 2021).

(PSI) exploits point scatterers with significant radar backscatter, collected over a long period (years) and characterized by strong stability over time in terms of reflectivity, providing a phase history of the point target (Ferretti et al., 2011, 2001, 2000).

The PSs are preferred "measurement points" due to their unique features that enable them to undertake precise displacement measurements (in the range of a few millimetres). Good reflectors are, for example, buildings, transportation routes (roads, railways), pylons, dams, bridges, etc. Subsequently, CH sites are suitable for applying such remote sensing methods.

Because they can only be found in targets that exhibit consistent reflecting characteristics over time, the number of PSs is constrained. Due to their physical makeup, bridges, railroads, and roads typically meet this requirement and can produce a lot of PSs. However, under some conditions, infrastructure assets' capacity to deliver steady backscattering over time may be jeopardised, resulting in either a whole or partial loss of PSs (Macchiarulo et al., 2023).

Essentially, PSI builds upon the principles of DInSAR, but with a specific emphasis on persistent scatterers. PSI focuses on scatterer detection, which is a complex process that identifies and isolates persistent scatterers from the SAR data. This involves analyzing the phase history of radar reflections from various targets to identify the ones that exhibit persistent and coherent behavior.

Regarding the ability to distinguish between the impacts of displacement and atmospheric signature, conventional DInSAR may present some limitations. By relaxing the typical baseline and temporal constraints and increasing the number of usable interferograms, PSI approaches are able to operate past these restrictions. These interferograms can then be used to derive mean trends over time from a huge history of interferograms. Reduced pixel density is the result of considering just the targets with adequate coherence ("User Guides - Sentinel-1 SAR - Interferometry - Sentinel Online," n.d.).

2.2.3.1 Use of Persistent Scatterer Interferometry (PSI)

An extensive natural network of "measurement points" enables the identification of both small- and large-scale deformation phenomena, such as faults, landslides, and subsidence that influence a particular building or structure. PSI has been widely used to investigate various risks, including landslides, and to use PS time-series analysis to reconstruct the history of deformations (Antoniadis et al., 2023; Antonielli et al., 2019; Bozzano et al., 2017; Del Ventisette et al., 2014; Strozzi et al., 2010).

Persistent Scatterer InSAR (PS-InSAR) and Small Baseline Subset InSAR (SBAS-InSAR), based on processing long stacks of satellite SAR imagery and identification of coherent or persistent scatterers, have been the most widely used InSAR techniques for detecting and analysing surface stability, structural deformation, and changes occurring in areas where archaeological sites are built. The structural stability of ancient monuments and underground constructions can be endangered by deformation, which the PS-InSAR techniques are capable of diagnosing in advance. Additionally, the PS-InSAR method and SAR photos can be used to create a precise average annual deformation rate map, aiding in the effective management of land in a CH area. Time-series data can also be used to demonstrate how a CH location deforms (Luo et al., 2019).

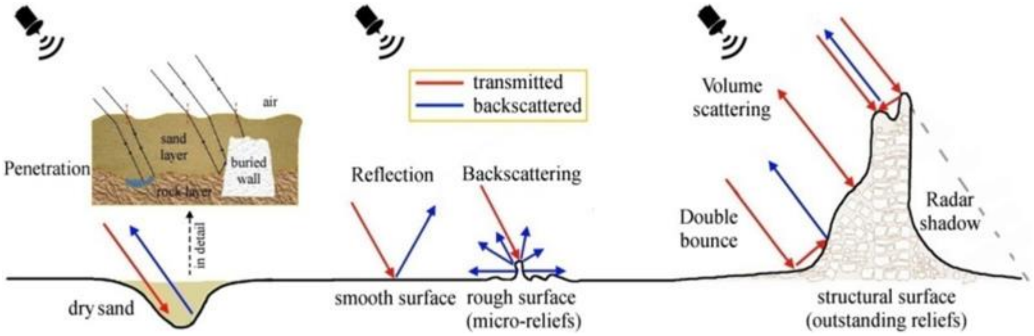

Figure 2-4 Model of the response of basic scattering mechanisms: from left to right, simplified models of volume scattering in soil penetration, single bounce (smooth surface), back scattering (surface roughness for archaeological microrelief) and double bounce volume scattering (walls or other outstanding reliefs (Luo et al., 2019).

2.2.3.2 Comparison between DInSAR and PSI

In summary, while both PSI and DInSAR utilize radar data to monitor ground deformation, PSI is specialized for tracking stable and persistent scatterers which are less affected by atmospheric and temporal changes over longer periods (months to years), thus providing higher accuracy results.

PSI is a particularly effective method for monitoring stable urban infrastructure, while it is less suitable for monitoring rapidly changing or temporally unstable areas. On the other hand, DInSAR is a broader technique, meant to capture a variety of deformation phenomena, including tectonic activity, landslides, volcanic deformation and urban subsidence. This method may have slightly lower accuracy compared to PSI since it is affected by atmospheric conditions, temporal decorrelation and other factors that create noise.

2.3 Remote sensing using airborne and terrestrial data – Photogrammetric methods

The primary use of photogrammetric data, which are limited to the visible spectrum, is to replicate the geometrical features of a main object. Terrestrial data-based remote sensing involves acquiring and analyzing information about the Earth's surface and environment using a combination of sensors and instruments deployed on aircraft or UAVs (Unnamed Aerial Vehicles) and on the ground. Unlike conventional remote sensing via satellites, these methods offer the advantage of close-range observations and measurements, allowing precise examination of various phenomena. Airborne and terrestrial remote sensing may involve techniques such as aerial photogrammetry and LiDAR (Light Detection and Ranging) employed for the generation of detailed 3D maps.

Regarding photogrammetry, the Structure-from-Motion method which operates under the basic tenets of stereoscopic photogrammetry, namely that 3D structure can be resolved from a series of overlapping, offset images (Westoby et al., 2012). Nevertheless, this method differs fundamentally from traditional photogrammetry in that it automatically calculates the geometry of the scene, as well as the position and orientation of the camera, without requiring the existence of predefined targets with known coordinates. This is achieved through a highly redundant, iterative bundle adjustment process, utilizing a database of features extracted from multiple overlapping images (Snavely et al., 2008). This technique is best suited for image sets with substantial overlap, in order to thoroughly capture the three-dimensional structure of the scene from multiple viewports or images derived from a moving sensor, as suggested by the name of the method itself (Westoby et al., 2012).

2.4 Machine Learning

By utilizing the capabilities of Machine Learning (ML), we are able to extract significant patterns, detect minute changes, and anticipate potential threats to these sites. ML algorithms provide an innovative solution to the challenges posed by cultural heritage monitoring using multi-type remote sensing (Hajj, 2021). This allows going beyond simple observation and take direct action to protect our cultural heritage for future generations.

In order to improve our ability to identify and characterize changes, automate feature extraction, foresee hazards, help decision-making, and improve interpretation, machine learning algorithms are being used in cultural heritage monitoring with multi-type remote sensing. More specifically, machine learning models can examine recent and historical remote sensing data to spot changes in the environment, buildings, and artifacts. In comparison to conventional techniques of feature extraction, ML algorithms learn to extract pertinent characteristics from the data, enabling more precise and reliable analysis.

ML algorithms that have been trained on historical data might anticipate possible dangers to culturally significant locations, such as erosion, urbanisation, or climate-related effects. Additionally, ML outputs may act as decision support systems, by giving stakeholders data-driven insights to direct conservation plans, resource allocation, and restoration initiatives. Finally, ML can support archaeologists and cultural specialists in the analysis of remote sensing data, assisting them in revealing hidden insights, comprehending the historical context, and providing accurate interpretations.

3. DATA FOR CONTINUOUS RISK MONITORING

In the ERA4CH project, all the satellite data for the case studies of Narni (Italy), Chania (Greece) and Strovolos (Cyprus) will be loaded into a dedicated repository. Moreover, data regarding specific geotechnical information as well as existing maps on civil engineering parameters of the aforementioned regions will be also uploaded to the repository.

In order to prospect CH sites, archive remote sensing data are frequently employed, especially for conflict zones or other sensitive locations where airborne and ground operations are prohibited or would be challenging to conduct. Additionally, today's historical aerial picture archives, provide as a "unique data source" that may be utilised to identify CH characteristics that have since been destroyed and other anthropogenic activity. Therefore, for archaeological purposes, historical data may be thought of as a low-cost substitute for contemporary aerial photography or for commercial satellite goods (Luo et al., 2019).

Data can be processed according to the methodologies described in the previous subsections.

3.1 Copernicus Space Programme Services

Copernicus builds on a constellation of satellites that makes a huge number of daily observations - taking advantage of a global network of thousands of lands, air, and marine-based sensors to create the most detailed pictures of Earth. The vast majority of data/information delivered by Copernicus is made available and accessible to any citizen, and any organization around the world on a free, full, and open basis. Several services for monitoring cultural landscapes are available through the Copernicus Space Programme[5].

- Land Monitoring Service (CLMS)

It furnishes geospatial data encompassing land cover, land use, vegetation status, water cycle, and surface energy factors, serving diverse users in Europe and globally for environmental terrestrial purposes. It aids applications in fields like urban planning, forestry, water and agriculture management.

- Climate Change Service (C3S)

It supports society by providing consistent and authoritative information about the past, present and future climate in Europe and the rest of the World.

- Emergency Management Service (EMS)

It offers data and maps for disaster management and emergency response, especially for earthquakes, fires, and floods. Copernicus EMS - Mapping can support all phases of the emergency management cycle: preparedness, prevention, disaster risk reduction, emergency response and recovery.

- Geohazards Thematic Exploitation Platform (G-TEP)

G-TEP is a platform that leverages satellite Earth observation data and methods to aid the geohazards community. It offers on-demand and systematic processing services, connects to various data sources including Copernicus and specific EO missions, and uses cloud computing for global tectonic monitoring. The platform links to the whole Copernicus Sentinels-1/2/3 repositories, high-resolution optical images, as well as to more than 70

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[5] https://www.copernicus.eu/en/copernicus-services

terabytes of EO data (ERS and ENVISAT archive), as well as to specialised data collections from EO missions including JAXA's ALOS-2, ASI's Cosmo-Skymed, and TerraSAR-X.

In order to monitor, manage and preserve cultural heritage landscapes, Copernicus services provide timely rapid mapping on the extent and severity of an event, reliable information on changes in land cover, vegetation patterns, and natural disasters, as well as land surface parameters, such as temperature, vegetation indices, and soil moisture. Overall, Copernicus Satellite Projects' sensors and solutions provide useful tools for monitoring cultural landscapes and can aid in their sustainable management and protection (“Copernicus Services | Copernicus,” n.d.).

3.2 Synthetic Aperture Radar (SAR) images for monitoring CH sites

The SAR data are excessively employed for the continuous monitoring of the risk of CH. SAR images have been available since 1992, when the first global systematic acquisition of SAR scenes was initiated by the European Space Agency using the ERS-1 satellite which was launched in July 1991 (“ERS at a glance,” n.d.). To generate a displacement map for a specific area, it is necessary to have at least 15 to 20 images that were captured under the same acquisition conditions, as suggested by (Crosetto et al., 2016). Moreover, the accuracy of estimating the average velocity and creating time-series data for displacement gets better as you have access to more images. These images, which can be processed using A-DInSAR methods, form what is known as an interferometric stack.

In the following figure (Figure 3-1) the SAR available satellites from 1991 until 2025 are depicted.

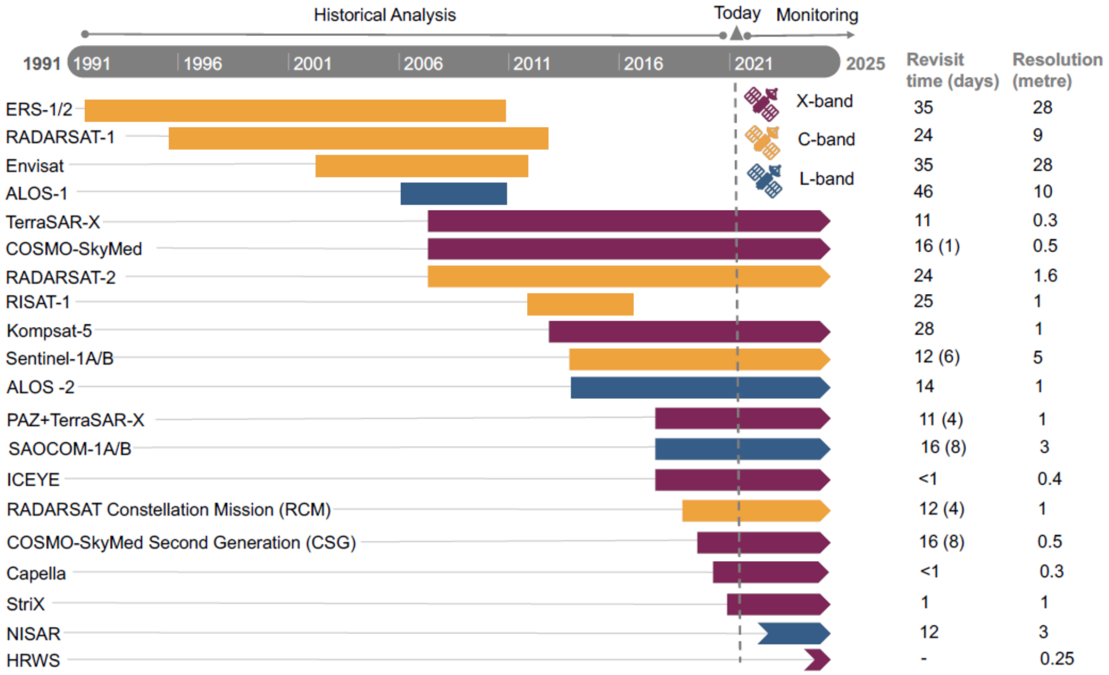

Figure 3-1 Timeline of past, present and future SAR missions between 1991 and 2025, and their main features (Macchiarulo et al., 2023)

Several space agencies have supported, and continue to support, different SAR missions such as:

- European Space Agency (ESA) with ERS-1, ERS-2, Envisat and Sentinel-1 satellites;
- Japan Aerospace Exploration Agency (JAXA) with JERS-1, ALOS-1 and ALOS-2;
- Canadian Space Agency (CSA) through Radarsat-1, Radarsat-2 and the future Radarsat constellation;
- Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR) by means of TerraSAR-X and TanDEM-X;
- Indian Space Research Organization (ISRO) with RISAT-1 and NISAR (w/ NASA);
- Comision Nacional de Actividades Espaciales with SAOCOM;
- Italian Space Agency (ASI) with the COSMO-SkyMed Constellation;
- Instituto National de Técnica Aeroespacial (INTA) with PAZ;
- Korea Aerospace Research Institute (KARI) with KOMPSat-5.

3.3 LiDAR Data

In theory, LiDAR and SAR are comparable since both technologies use light pulses to measure how long it takes for backscattered echoes to return and how much of the original energy comes back. (Masini and Lasaponara, 2013) LiDAR can determine target parameters through location, radial velocity, reflection, and scattering characteristics as well as measure range and orientation. LiDAR devices can be deployed on terrestrial, aerial, or satellite platforms. For example, Terrestrial Laser Scanning (TLS) and Aerial Laser Scanning (ALS) offer 3D information on the topography of the Earth's surface (Wang et al., 2016).

A digital surface model (DSM) that provides an estimate of the top of a canopy, the height of man-made structures, or the height of the water surface, and a DTM that displays the topographic variability of the bare earth, seafloor, or other water body bed, are usually the two datasets included in products derived from classified airborne LiDAR point clouds.

Airborne LiDAR has been effectively used to identify archaeological sites and study patterns all over the world as a consequence of the efforts of archaeologists and professionals in understanding the physical foundation of LiDAR echo reflections. Currently, aerial LiDAR-based CH applications are mostly focused on the use of full-waveform systems, which allow for the creation of very precise surface models as well as the detection of ancient buildings, earthworks, or submerged sites even when they are hidden by thick vegetation or are underwater. Discrete model LiDAR, which was referred to as a "conventional" system, has been used successfully in various instances of archaeological prospecting. Typically, a green LiDAR system (wavelength of 532 nm), also known as bathymetric LiDAR, enters the water column to scan the bottom, while a near-infrared LiDAR system (wavelength of 1064 nm or 1550 nm), also known as topographic mapping LiDAR, penetrates the tree canopy to acquire topography information (Luo et al., 2019).

Using shaded DSMs produced from filtered and strip-adjusted point clouds created from LiDAR readings, LiDAR techniques are also employed for locating and monitoring underwater archaeological sites (Lasaponara et al., 2011; Luo et al., 2019; Masini and Lasaponara, 2013),

3.4 Multispectral and hyperspectral imagery

For crucial applications in the protection and monitoring of CH, hyperspectral remote sensing is a critical instrument. Through the use of hyperspectral images, this advanced technology allows us to get clear insights into the structure of the Earth's surface. Hyperspectral sensors collect data over hundreds of precisely tuned spectral bands, setting them apart from traditional multispectral sensors. The ability to create complex pictures with each pixel including the full spectrum of the underlying surface material at that specific spot is made possible by this richness of information.

In terms of monitoring cultural assets, hyperspectral imaging has a wide range of applications. Their spectral resolution is one of their most outstanding features. This improved resolution makes it possible to distinguish between different types of materials and even makes it easier to identify subtle and complex spectral characteristics that could otherwise go undetected.

By employing hyperspectral data, it is feasible to map different kinds of ruins, carefully monitor how monuments change over time, identify and classify various types of deterioration, and continuously check on the structural integrity of cultural heritage sites. This is made possible by the extraction of a variety of properties from remote sensing images, that combined provide a comprehensive perspective of the submerged archaeological remains. These features range from spectral and spatial to radiometric and temporal. Remarkably buried archaeological artefacts have the ability to change the soil's chemical, physical, and biological properties in noticeable ways.

The periodic patterns in the recorded spectra hold the key to archaeological detection. These spectral differences can be carefully examined to reveal any traces of archaeological characteristics. It becomes possible to intentionally choose an optimal spectral range in situations when the predominant land cover above archaeological sites is known, especially in such cases. This selection procedure is essential for maximising the effectiveness of archaeological studies carried out using remote sensing techniques.

Multi/hyperspectral and thermal sensors have been used to monitor on the surfaces of a few different structures, as well as the immediate area around them (such as road shoulders, dams, nearby hills, and so on) (Peleli et al., 2021). In terms of sensor use, the conceptual model will make use of the advantages of passive (multispectral, hyperspectral, and thermal cameras) and active instruments (i.e., SAR), as well as the best processing and data integration techniques based on image processing and time series analysis, photogrammetric analysis, SAR differential interferometry, and cutting-edge ML, like deep CNN.

3.5 Limitations and challenges

Passive remote sensing

Historical aerial and satellite images have become extremely useful resources for monitoring cultural heritage (CH) sites. Their use, however, has only included manually interpreting grayscale pictures. Fortunately, there are ways to improve these photos, which makes it easier to discover their concealed information. Moreover, spectral imaging has become an effective way to overcome the drawbacks of grayscale photography. It has the exceptional capacity to simultaneously collect data over a wide range of wavelengths. The deliberate capturing of pictures in the Near-Infrared (NIR) and Shortwave Infrared (SWIR) areas makes up for the occasional loss of delicate spectral information that might occur with multispectral photography owing to averaging.

These spectral locations continue to be useful for identifying variations in reflectance across different types of soil and vegetation health. Additionally, the photogrammetric extraction of 3D data, particularly from historic stereo pairs of photographs, has great utility. This procedure makes it possible to produce high-resolution historical Digital Elevation Models (hDEMs) that are designed exclusively for archaeological studies. The creation of dense point clouds from aerial pictures has emerged as a competitive substitute for active airborne LiDAR approaches, regardless of whether a DSM or DTM is the required output. Narrowband hyperspectral images in the field of spectral imaging have shown to be very useful. It can improve how noticeable archaeological sites are in the environment and offer comprehensive details about how they are and their surroundings. Utilising the inherent reflectance and absorption characteristics of each feature's own spectral signature, this is accomplished. It is essential to remember that archaeological features lack spectral signatures that may be used widely for identification and are universally unique (Luo et al., 2019).

Active remote sensing

LiDAR has revolutionized the field of archaeology by providing a non-invasive and highly accurate method for mapping and understanding ancient landscapes. It has the potential to uncover countless hidden archaeological relics and enhance our knowledge of the past. In order to examine and recreate past urban and settlement patterns in specific regions and to direct the active automated finding of undiscovered archaeological sites, airborne LiDAR data is useful. Regarding the airborne LiDAR systems, the identification of archaeological characteristics and their interpretation depend on the reduction of signal distortion and misclassification. Semantic segmentation is mostly employed in urban or even interior situations and is a cutting-edge classification technique for 3D LiDAR point clouds. Due to the complexity of the field archaeology setting, semantic segmentation is currently challenging to implement. LiDAR can have difficulty penetrating dense vegetation or thick canopy cover, making it less effective in heavily forested areas. In such environments, important archaeological features may remain hidden. Moreover, the ground resolution of LiDAR data may not always be sufficient to identify smaller or subtle archaeological features. Some details may be missed, requiring additional on-the-ground surveys. Despite these limitations, LiDAR remains a valuable tool in archaeology when used in conjunction with other survey methods and careful data analysis. It has the potential to transform our understanding of ancient landscapes and archaeological sites, but it should be employed judiciously, taking into account its strengths and weaknesses (Luo et al., 2019).

On the other hand, according to the imaging parameters of frequency, incidence angle, and polarisation, SAR backscattering offers details on surface properties. According to (Balz et al., 2016), SAR would need a spatial resolution that is around two to three times better than optical images in order to clearly identify burial mounds. Furthermore, surface features and moisture content severely constrain SAR's capacity to penetrate surfaces. While SAR can penetrate some types of vegetation and soil, its ability to see through dense forests or highly conductive materials is limited. The extent to which it can penetrate the ground or vegetation depends on the frequency and wavelength of the SAR system. Also, it's important to note that while SAR has many advantages, it also has limitations, such as the need for specialized equipment and expertise. Despite these drawbacks, SAR is nevertheless an important tool for archaeology, especially when combined with other remote sensing methods. Due to its ability to see through some impediments and its all-weather capabilities, it is a useful type of data for locating and studying historic monuments and landscapes.

4. REMOTE SENSING METHODOLOGIES AND DATA IN THE ERA4CH TEST AREAS

The geohazard assessment project focuses mostly on tracking and examining the geological activity in certain case study locations. The three case studies are Chania (Greece), Narni (Italy), and Strovolos (Cyprus). The project team is working in these areas to understand and address possible geological hazards and related phenomena through research, data collection, and analysis. A targeted strategy enables in-depth research and identification of any geohazard that could exist in these locations. The final output of the ERA4CH platform will be risk maps of the historical centres showing the impact of the simulated earthquake events on the urban texture with the classification of the areas more or less subject to damages.

Buildings' categorization will make it possible to identify probable collapse mechanisms and the key acceleration that might lead to a misinterpretation of the process. Only geometry and boundary condition data based on visual estimations are required as a first-level technique to determine the acceleration, making data given by SAR technologies the most valuable. Different damage probabilities will be considered when taking into account the proper boundary conditions for the projected displacements.

The following figure shows the exact methodology that is going to be followed in the context of the project and how the data are going to be implemented for the development of the final output of the ERA4CH platform.

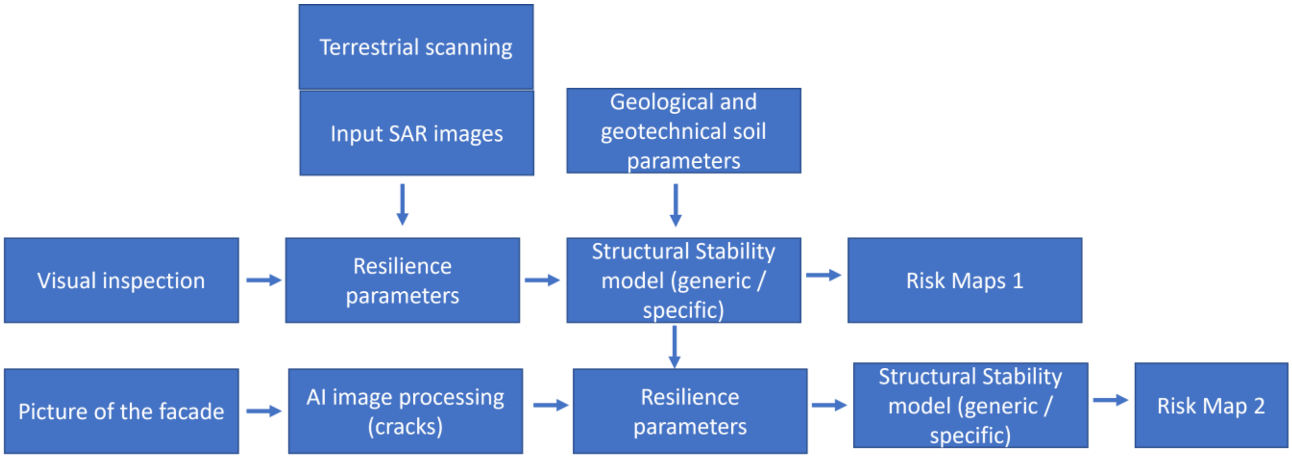

Figure 4-1 The ERA4CH methodology

The data that are going to be utilized in this project can be collected from the Copernicus Open Access Hub[6]). Copernicus Hub provides services that concern sea, land, atmosphere, safety, and emergencies. Registration in Open Hub is required in order to access all services. Having successfully created the account all the services are available, in which all requirements for the acquisition of satellite images must be added. After inserting or selecting the area of interest, the option of "Insert search criteria" is available, providing the opportunity to specify the picture requirements.

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[6] https://scihub.copernicus.eu/dhus/#/home

The products from missions Sentinel-1, Sentinel-2, and Sentinel-3 are available on this platform. Sentinel-1 mission SAR pictures are mostly utilised for inland movement estimates. We choose the time frame for the research or sensing and look at the Sentinel-1 mission. To be consistent with the data in the analysis, the Product type, Polarisation, Sensor Mode, and Satellite Platform must be filtered.

The figures below demonstrate the interface of the Copernicus Open Access Hub and the case study regions.

Municipality of Narni

The Municipality of Narni is a local administrative division in Italy, located in the region of Umbria. It encompasses the town of Narni, which is known for its rich history and picturesque old city.

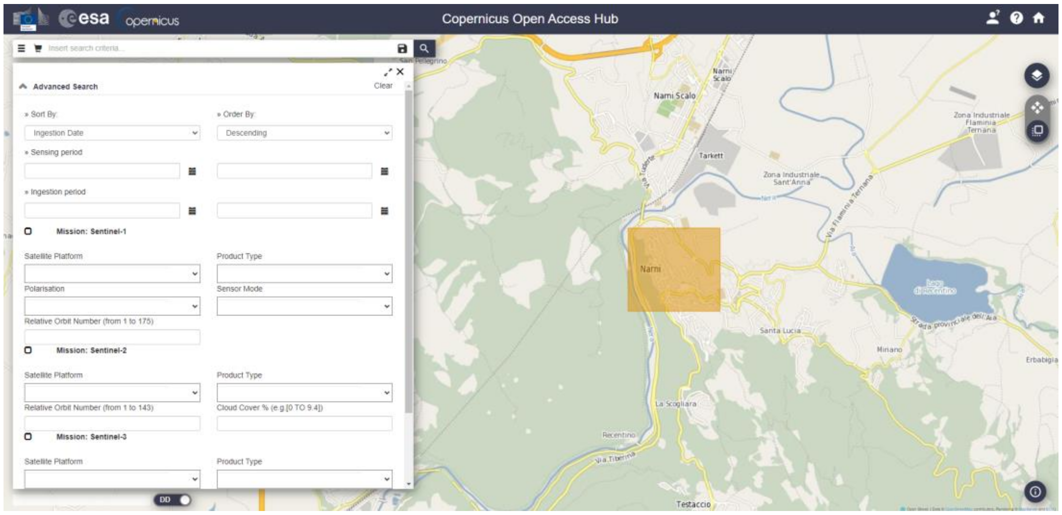
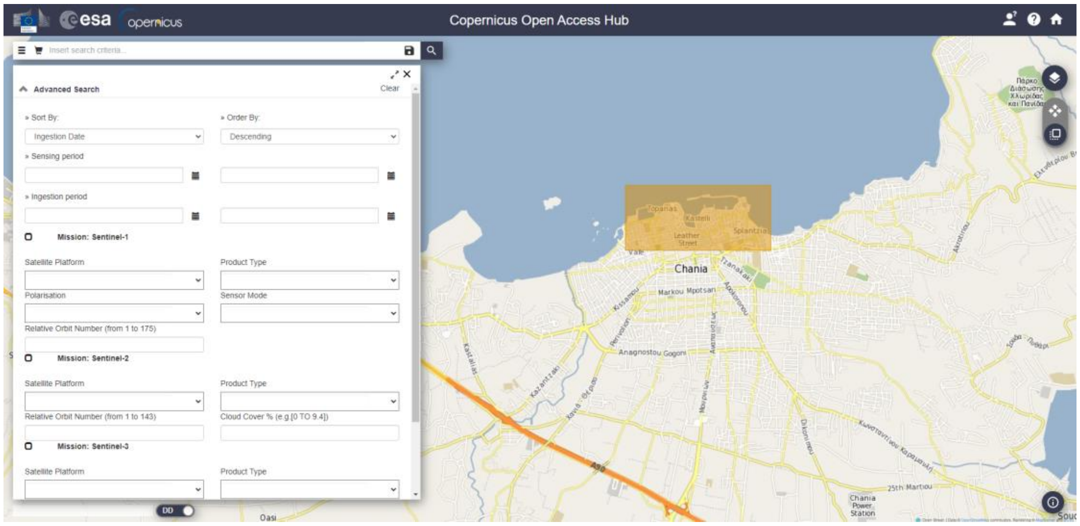

Sort By: Ingestion Date
Order By: Descending

Figure 4-2 Copernicus Open Access Hub focused on the area of Narni

Municipality of Chania

The Municipality of Chania is located on the island of Crete, Greece. Its old town, also known as the Venetian Harbor of Chania. Chania's old town is renowned for its rich history, traditional architecture, and vibrant atmosphere.



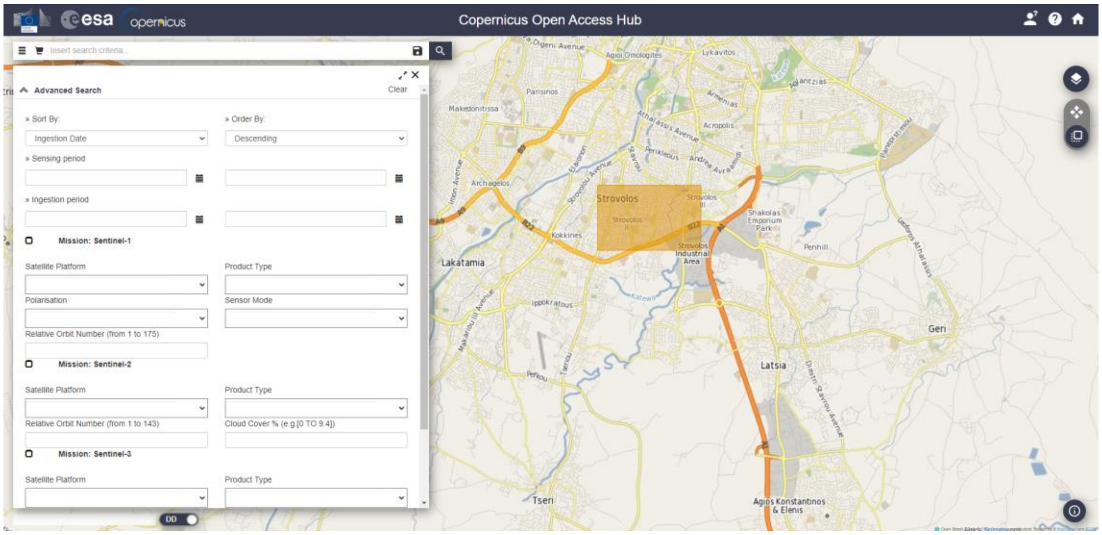
» Sort By: Ingestion Date

» Order By: Descending

Figure 4-3 Copernicus Open Access Hub focused on the area of Chania

Municipality of Strovolos

Strovolos is a municipality of Cyprus in the district of Nicosia from 1986 and is part of the metropolitan area of Nicosia.



» Sort By: Ingestion Date

» Order By: Descending

Figure 4-4 Copernicus Open Access Hub focused on the area of Strovolos

5. CONCLUSION

In conclusion, this document Illustrates the pivotal role that remote sensing methodologies fulfil, combined with their resulting data in supporting cultural heritage risk assessment and management, serving as a thorough guide and reference for the ERA4CH project. Moreover, it is highlighted how satellite remote sensing might be a useful tool in this effort offering a road map for putting these ideas into practice to get long-lasting outcomes in cultural asset protection and conservation(Moise et al., 2021).

One of the key takeaways from this report relies on the recognition of satellite remote sensing as a potent and versatile tool in the protection and conservation of cultural assets. The ability to monitor and assess the condition of heritage sites from above not only enhances our understanding but also provides early warnings and critical data for more informed and integrated decision-making.

All of the aforementioned expertise will be tested in the case studies of the project in order to identify the most vulnerable sites to seismic activity, aiming to produce a risk map, in order to preserve the historical monuments from further damage and deterioration.

6. REFERENCES

19th General Assembly 2017 - International Council on Monuments and Sites [WWW Document], n.d. URL https://www.icomos.org/en/about-icomos/governance/general-information-about-the-general-assembly/list-of-general-assemblies/future-annual-general-assemblies-2016-2017 (accessed 9.20.23).

Antoniadis, N., Alatza, S., Loupasakis, C., Kontoes, C. (Haris), 2023. Land Subsidence Phenomena vs. Coastal Flood Hazard—The Cases of Messolonghi and Aitolikon (Greece). Remote Sens. 15, 2112. https://doi.org/10.3390/rs15082112

Antonielli, B., Mazzanti, P., Rocca, A., Bozzano, F., Dei Cas, L., 2019. A-DInSAR Performance for Updating Landslide Inventory in Mountain Areas: An Example from Lombardy Region (Italy). Geosciences 9, 364. https://doi.org/10.3390/geosciences9090364

Balz, T., Caspari, G., Fu, B., Liao, M., 2016. Discernibility of Burial Mounds in High-Resolution X-Band SAR Images for Archaeological Prospections in the Altai Mountains. Remote Sens. 8, 817. https://doi.org/10.3390/rs8100817

Bouaraba, A., Aichouche, B.A., Closson, D., 2018. Drastic Improvement of Change Detection Results with Multilook Complex SAR Images Approach. Prog. Electromagn. Res. C 82. https://doi.org/10.2528/PIERC17112701

Bozzano, F., Mazzanti, P., Perissin, D., Rocca, A., De Pari, P., Discenza, M.E., 2017. Basin Scale Assessment of Landslides Geomorphological Setting by Advanced InSAR Analysis. Remote Sens. 9, 267. https://doi.org/10.3390/rs9030267

Copernicus Services | Copernicus [WWW Document], n.d. URL https://www.copernicus.eu/en/copernicus-services (accessed 9.20.23).

Crosetto, M., Monserrat, O., Cuevas-González, M., Devanthéry, N., Crippa, B., 2016. Persistent Scatterer Interferometry: A review. ISPRS J. Photogramm. Remote Sens., Theme issue "State-of-the-art in photogrammetry, remote sensing and spatial information science" 115, 78–89. https://doi.org/10.1016/j.isprsjprs.2015.10.011

Del Ventisette, C., Righini, G., Moretti, S., Casagli, N., 2014. Multitemporal landslides inventory map updating using spaceborne SAR analysis. Int. J. Appl. Earth Obs. Geoinformation 30, 238–246. https://doi.org/10.1016/j.jag.2014.02.008

Earth Science Data Systems, N., 2020. What is Synthetic Aperture Radar? [WWW Document]. Earthdata. URL https://www.earthdata.nasa.gov/learn/backgrounders/what-is-sar (accessed 9.20.23).

ERS at a glance [WWW Document], n.d. URL https://www.esa.int/Applications/Observing_the_Earth/ERS_at_a_glance (accessed 9.20.23).

Ferretti, A., Fumagalli, A., Novali, F., Prati, C., Rocca, F., Rucci, A., 2011. A New Algorithm for Processing Interferometric Data-Stacks: SqueeSAR. IEEE Trans. Geosci. Remote Sens. 49, 3460–3470. https://doi.org/10.1109/TGRS.2011.2124465

Ferretti, A., Prati, C., Rocca, F., 2001. Permanent scatterers in SAR interferometry. IEEE Trans. Geosci. Remote Sens. 39, 8–20. https://doi.org/10.1109/36.898661

Ferretti, A., Prati, C., Rocca, F., 2000. Nonlinear subsidence rate estimation using permanent scatterers in differential SAR Interferometry. Geosci. Remote Sens. IEEE Trans. On 38, 2202–2212. https://doi.org/10.1109/36.868878

Goal 11 | Department of Economic and Social Affairs [WWW Document], n.d. URL https://sdgs.un.org/goals/goal11 (accessed 9.20.23).

Hajj, H.E., 2021. Interferometric SAR and Machine Learning: Using Open Source Data to Detect Archaeological Looting and Destruction 4, 47–62. https://doi.org/10.5334/jcaa.70

Hanssen, R., 2001. Radar Interferometry Data Interpretation and Error Analysis, Remote Sensing and Digital Image Processing. https://doi.org/10.1007/0-306-47633-9

Lasaponara, R., Coluzzi, R., Masini, N., 2011. Flights into the past: full-waveform airborne laser scanning data for archaeological investigation. J. Archaeol. Sci., Satellite remote sensing in archaeology: past, present and future perspectives 38, 2061–2070. https://doi.org/10.1016/j.jas.2010.10.003

Luo, L., Wang, X., Guo, H., Lasaponara, R., Zong, X., Masini, N., Wang, G., Shi, P., Khatteli, H., Chen, F., Tariq, S., Shao, J., Bachagha, N., Yang, R., Yao, Y., 2019. Airborne and spaceborne remote sensing for archaeological and cultural heritage applications: A review of the century (1907–2017). Remote Sens. Environ. 232, 111280. https://doi.org/10.1016/j.rse.2019.111280

Macchiarulo, V., Milillo, P., Blenkinsopp, C., Reale, C., Giardina, G., 2023. Multi-temporal InSAR for transport infrastructure monitoring: recent trends and challenges. Proc. Inst. Civ. Eng. - Bridge Eng. 176, 92–117. https://doi.org/10.1680/jbren.21.00039

Masini, N., Lasaponara, R., 2013. Airborne Lidar in Archaeology: Overview and a Case Study, in: Murgante, B., Misra, S., Carlini, M., Torre, C.M., Nguyen, H.-Q., Taniar, D., Apduhan, B.O., Gervasi, O. (Eds.), Computational Science and Its Applications – ICCSA 2013, Lecture Notes in Computer Science. Springer, Berlin, Heidelberg, pp. 663–676. https://doi.org/10.1007/978-3-642-39643-4_48

Massonnet, D., Feigl, K.L., 1998. Radar interferometry and its application to changes in the Earth’s surface. Rev. Geophys. 36, 441–500. https://doi.org/10.1029/97RG03139

Moise, C., Dana Negula, I., Mihalache, C.E., Lazar, A.M., Dedulescu, A.L., Rustoiu, G.T., Inel, I.C., Badea, A., 2021. Remote Sensing for Cultural Heritage Assessment and Monitoring: The Case Study of Alba Iulia. Sustainability 13, 1406. https://doi.org/10.3390/su13031406

Peleli, S., Kouli, M., Marchese, F., Lacava, T., Vallianatos, F., Tramutoli, V., 2021. Monitoring temporal variations in the geothermal activity of Miocene Lesvos volcanic field using remote sensing techniques and MODIS – LST imagery. Int. J. Appl. Earth Obs. Geoinformation 95, 102251. https://doi.org/10.1016/j.jag.2020.102251

SNAP Download – STEP, n.d. URL https://step.esa.int/main/download/snap-download/ (accessed 9.20.23).

Snavely, N., Seitz, S., Szeliski, R., 2008. Modeling the World from Internet Photo Collections. Int. J. Comput. Vis. 80, 189–210. https://doi.org/10.1007/s11263-007-0107-3

Strozzi, T., Delaloye, R., Kääb, A., Ambrosi, C., Perruchoud, E., Wegmüller, U., 2010. Combined observations of rock mass movements using satellite SAR interferometry, differential GPS, airborne digital photogrammetry, and airborne photography interpretation. J. Geophys. Res. Earth Surf. 115. https://doi.org/10.1029/2009JF001311

Tayeb, S., Abed, M., Mebarki, A., Lazecky, M., 2022. Earthquake-induced landslide monitoring and survey by means of InSAR. Nat. Hazards Earth Syst. Sci. 22, 1609–1625. https://doi.org/10.5194/nhess-22-1609-2022

User Guides - Sentinel-1 SAR - Interferometry - Sentinel Online [WWW Document], n.d. . Sentin. Online. URL https://copernicus.eu/user-guides/sentinel-1-sar/product-overview/interferometry (accessed 9.20.23).

Wang, Y., Li, G., Ding, J., Guo, Z., Tang, S., Wang, C., Huang, Q., Liu, R., Chen, J.M., 2016. A combined GLAS and MODIS estimation of the global distribution of mean forest canopy height. Remote Sens. Environ. 174, 24–43. https://doi.org/10.1016/j.rse.2015.12.005

Westoby, M.J., Brasington, J., Glasser, N.F., Hambrey, M.J., Reynolds, J.M., 2012. ‘Structure-from-Motion’ photogrammetry: A low-cost, effective tool for geoscience applications. Geomorphology 179, 300–314. https://doi.org/10.1016/j.geomorph.2012.08.021

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