

Chapter 3

Preserving the Past from Space: An Overview of Risk Estimation and Monitoring Tools

Rosa Lasaponara and Nicola Masini

Abstract Earth observation (EO) technologies can enable advanced performance and new operational applications specifically addressed to security and risk (see, for example Copernicus program and Sentinel missions), also including the monitoring and preservation of heritage sites. EO techniques can provide operative tools for supporting heritage protection, conservation, and presentation identifying and monitoring factors that can adversely affect the property (see, for example, those listed in the UNESCO web site <http://whc.unesco.org/en/factors/>). In this context, UNESCO, in partnership with some space agencies of the world (NASA, ESA, DLR, ASI, CNES, Chinese), over the years has strongly promoted the use of space technologies to assess the state of conservation of cultural and natural heritage sites. Nevertheless, even if the potential of EO technologies for assessing and monitoring natural and man-made disasters is well known, still today the application of RS data in operational disaster management and monitoring is a difficult task. To move from scientific to operational applications there are gaps to be filled and needs to be addressed. To improve the risk estimation and management based on remote sensing data, it is particularly important to set up operational approaches and methods for diverse applications and risks, with protocols and quantitative evaluations of accuracy and reliability.

Keywords Optical satellite remote sensing • Archaeology • Proxy indicator • Prediction models • Image enhancement

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3.1 Introduction: Context Definition

The preservation of cultural heritage is a pressing issue, especially for the territories subjected to a long period of human action that has adversely influenced both environment and landscape, producing a significant deterioration of archaeological features and alteration of historical landscape. The preservation and enhancement of natural and cultural heritage, including landscape, is today one of the topics of great economic and social significance. It is a strategic priority not only to transmit cultural treasure and evidences of the human past to future generations (for more detail, see Masini and Lasaponara 2016, this volume) but also to exploit them as a strategic and valuable economic asset, if inspired to sustainable development strategies. Cultural heritage can be a resource for economic development based on the principles of sustainable use of resources, not only for the benefit of society but also as a useful source of human development. This is an extremely important key factor for the countries that are owners of an extraordinary cultural legacy which must be preserved from the significant potential alterations from anthropogenic activities having a significant effect upon atmosphere, water, soil, and in turn on heritage and landscape. In this context, systematic monitoring activities may provide effective information and tools for assessing threats and risks on historical buildings, landscape, and buried remains.

In this context, it is important to highlight that cultural heritage and historical landscapes, especially where heavily influenced by human activities, have to be systematically monitored and accordingly managed and preserved.

Today, as also highlighted by UNESCO (Fig. 3.1), cultural heritage is “increasingly threatened with destruction not only by the traditional causes of decay, but also by changing social and economic conditions which aggravate the situation with even more formidable phenomena of damage or destruction” (from the general conference of the United Nations Educational, Scientific and Cultural Organization meeting in Paris from 17 October to 21 November 1972, at its 17th session, available online (<http://whc.unesco.org/en/conventiontext/>)).

According to UNESCO the factors that most of all threaten cultural heritage sites are these:

1. Urban sprawl
2. Pollution
3. Biological resource use/modification
4. Physical resource extraction
5. Local conditions affecting physical fabric
6. Deliberate destruction and vandalism (Fig. 3.2)
7. Social/cultural uses of heritage
8. Climate change
9. Severe weather events (Fig. 3.3)
10. Sudden ecological or geological events
11. Management and institutional factors
12. Transportation and utilities infrastructure



Fig. 3.1 World heritage sites in danger (<http://whc.unesco.org/en/danger/>)

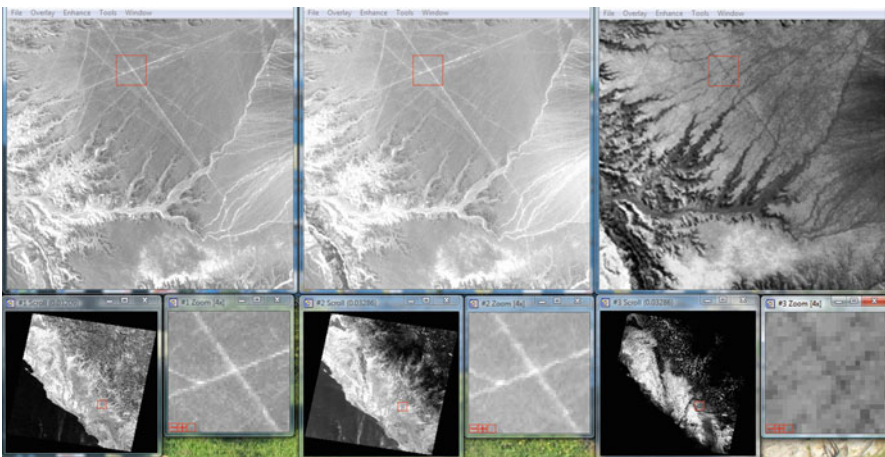


Fig. 3.2 Nasca lines threatened by vandalism and other human activities. The picture shows some detail from ASTER satellite data of the geoglyphs at different scales and spectral bands (VNIR, SWIR, TIR)

13. Invasive/alien or hyperabundant species

14. Terrorism or civil unrest

In past decades, many countries across the world have been involved and are today experiencing increasing frequency and impact of disasters, such as extreme



Fig. 3.3 Metaponto on the Ionian coast of Southern Italy: detail of the archaeological site affected by floods

hydrometeorological events, most probably related to climate change, floods, landslides, earthquakes, volcano eruptions, fires, uncontrolled urbanization, and air pollution.

To face the increasing frequency and adverse impact of disasters it is necessary to set up systematic monitoring activities and tools to identify issues and changes that can destroy or deteriorate heritage, increasing its vulnerability. This need may require the use of heterogeneous data essential to identify the major threats as well as to reconstruct the historical landscape and to compare it with the current one, so as to detect remains of the past, analyze the transformations, and detect ongoing changes and potential threats.

Although cultural heritage sites are documented and preserved, to date there have been limited monitoring actions and documentation of how cultural heritage sites are affected by the recent increasing impact of both natural and man-made disasters.

The potential of remote sensing technologies for assessing and monitoring natural and man-made disasters is well known, even if the application of remote sensing (RS) data in operational disaster management and monitoring is still a difficult task. There are gaps to be filled and a need to move from scientific to operational applications. In the past 20 years, the improved performance offered by space optical and radar sensors have opened the possibility of using RS data and tools for a large variety of applications ranging from landslide and subsidence to surface deformation, land cover degradation, flood, forest fire, volcanic eruptions, air pollution, and degradation phenomena.

At present it is particularly important to also improve risk estimation, mitigation, and management using information and data from remote sensing to set up operational approaches and methods for diverse applications and risks, as well as protocols and quantitative evaluations of their accuracy and reliability.

These needs and gaps have been also recently highlighted by ICOMOS (http://www.iccom.org/ifrcdn/pdf/ICCROM_17_RiskPreparedness_en.pdf). Examples of the most critical and urgent needs to preserve cultural heritage are listed here:

- Environmental assessment and monitoring (pollution, climate change, seismic risk)
- Anthropogenic pressure evaluation and management
- Telesurvey and Geographic Information Systems (GIS) for protection and management of tangible cultural heritage
- Prenormative studies for the guaranteed protection and management of tangible cultural heritage
- Study of environmental changes over time (Fig. 3.4)

A preventive approach against extreme natural events (seismic events, flooding, storms, landslides, fire) and measures of “first aid” requires these assessments:

- Changes in hydrogeological conditions in the ground: technologies for stabilizing historic structures
- Best conservation practices against specific attacks (physical, chemical, biological) to prevent damage of specific materials
- Intelligent multisensor systems for early warning (modeling, local network for monitoring systems), including tediagnosis

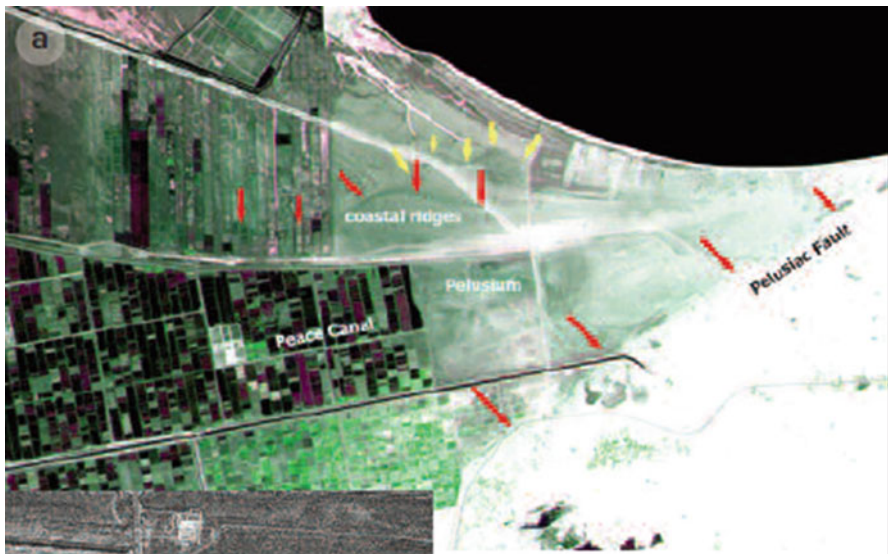


Fig. 3.4 Pelusium in Northern Egypt. ASTER satellite imagery indicates traces of the coastal regression and the Pelusiac fault, which extends southwest from the Levant to the northwest part of Sinai and ends on the eastern extent of the Nile Delta (Lasaponara and Masini 2015)

- Techniques for inventory, cataloguing, and traceability of cultural heritage objects

With these requirements:

- Critical levels of synergic pollutants in a context of environmental conditions (indoor/outdoor)
- Impact of climate change on materials and structures and adaptation of technologies to mitigate negative effects
- New solutions for development, assessment, and reporting of analysis protocol for the time effects evaluation of treatments (e.g., cleaning, biocides) and materials
- Web mapping and web GIS innovative tools for the telemonitoring and remote control of archaeological sites and cultural landscapes
- Development of advanced systems for telesurvey and remote fruition of underwater cultural heritage
- Preservation of twentieth-century military heritage: objects, buildings, and landscapes
- Safeguard of areas of archaeological interest with particular reference to crop mark sites (Fig. 3.5)

The different areas of intervention for cultural heritage require the availability of rigorous information for study and documentation, protection and conservation, monitoring, risk assessment, and management.



Fig. 3.5 Crop marks: proxy indicators of the presence of archaeological buried sites that are threatened by wind turbines. The site is in Apulia (Southern Italy)

For these aims it is necessary to improve capacity in the use of remote sensing technologies and data to monitor the state of conservation of cultural heritage, moving from scientific exercises to operational applications and tools.

3.2 Environmental Assessment and Monitoring for Preservation of Cultural Heritage

Satellites provide reliable tools not only for the identification but also for the analysis, monitoring, and management of landscape resources, as well as for supporting the conservation (at least from a digital aspect) of the features that define the cultural identity of a specific territory.

Earth observation (EO) is being successfully used for providing ongoing monitoring of natural and cultural sites, for assessing natural and man-made risks including emerging threats to heritage sites. The current availability of long-term satellite time series provides an excellent tool to observe and monitor changes from a global view down to a local scale. National (DLR, CNES, ASI, JAXA) and international space agencies, such as NASA and ESA, provide valuable satellite data very useful for capturing regional environmental changes along with the impact induced by human activities at a site level. In particular, from NASA website satellite time series (as AVHRR, SPOT-VEGETATION, MODIS, Landsat TM, etc.) are available free. More recently, ESA delivers Sentinel products and open source software tools specifically set up for processing active and passive data. Moreover, the availability since 2000 of very high resolution (VHR) data with spatial resolution less than 1 m up to pixels at 30 cm (TERRA-SAR, WorldView-3, today) enables the creation of accurate and updated maps.

Satellite images provide “a means to improve the information flow and communication among site managers and conservation authorities: “an image is worth a thousand words” (UNESCO web-site site http://www.unesco.org/science/remotesensing/?id_page=74&lang=en).

Many national, regional, and global assessments of environmental degradation were undertaken during the past 30 years, including soil, subsoil, water, vegetation degradation, urban expansion, and atmospheric pollutants. However, available procedures for the assessment of environmental degradation are still unsatisfactory because these methods are often too costly for surveying large areas and rely on specific components of the degradation process without being able to integrate them in a unique process. The availability of satellite time series provides useful tools for capturing environmental degradation processes at different spatial and temporal scales. Satellite time series enable the monitoring of subtle long-term variations of important parameters, such as surface temperature, moisture content, vegetation indices, and aerosols.

Detecting temporal changes by observing surfaces at different times is one of the most important applications of satellite sensors because they can provide

multidate imagery at short intervals on a global scale. National and international agencies provide long time series of the aforementioned products obtained from MODIS, AVHRR, VEGETATION, and also Landsat TM data useful to assess environmental degradation and capture changes from global to local-scale change detection analyses.

Detecting regions of change in images of the same scene taken at different times has widespread interest because of the large number of applications in diverse disciplines. Important applications of change detection include remote sensing (see, for example, Bruzzone and Prieto 2002; Collins and Woodcock 1996; Huertas and Nevatia 2000), civil infrastructure (Landis et al. 1999; Nagy et al. 2001), and underwater sensing (Edgington et al. 2003; Singh 1989).

Earth observation data provide important and useful spatial and temporal information that can be used to make better decisions, design policies, and address problems that range in scale from local to global. Costs go down, quality increases, and data become increasingly available for important everyday applications.

Despite the diversity of applications, change detection researchers employ many common processing steps and core algorithms [see the overviews on change detection by Singh (1989) and Coppin and Bauer (1996)]. Starting from early application, nowadays much experience has already been accumulated in exploring change detection techniques for medium/high spatial resolutions, but very few methods can be found for the new generation of very high spatial resolution satellite sensors: passive such as IKONOS, QuickBird, or GeoEye, or active such as Cosmo SkyMed and TERRA SAR.

The availability of VHR data greatly increases the potentiality in monitoring changes from space, but at the same time, the relatively large amount of data may induce a decrease in our ability, because VHR data better resolve the details of changes but present a new challenge over other data processing approaches and methodologies. The large amount of data stored in VHR satellite sensors must be analyzed using advanced procedures; this makes it possible to overcome the mixed pixel problem inherent with more moderate resolution satellite systems.

3.2.1 Landscape Degradation: Nonnative Plant Invasion

Identification of nonnative plants by monitoring is quite complex and difficult to accomplish in situ; moreover, field surveys are time consuming and expensive. The use of satellite remote sensing techniques can effectively support the detection and categorization of areas characterized by invasion of alien plants as well as the identification of other vulnerable habitats.

Analysis based on multitemporal and multisensor remote sensing data can provide operational tools for the monitoring and mapping of invasive plants, which are generally quite aggressive, characterized by fast and continued spread, so that they reduce and strongly compromise local biodiversity.

Several investigations have pointed out that satellite imagery can suitably help us to control and prevent exotic plant populations as well as to effectively and systematically monitor vegetation dynamics and identify anomalies.

Maps based on the multitemporal investigation of satellite-based parameters, such as the commonly used normalized difference vegetation index (NDVI) enhances the signal of photosynthetically active reactions, providing information on changes in ecosystems as well as on the types and quantity of vegetation cover.

3.2.2 Landscape Degradation: Soil Erosion

Remote sensing is now recognized worldwide as an effective, accurate, and economical method to monitor changes in land cover from the global down to a local scale (Fig. 3.6). For large areas, the use of remote sensing data is an essential tool for change monitoring and mapping as well as for monitoring and evaluating the ongoing land degradation processes, which have been particularly evident in the past 30 years. The so-called erosion processes affect large areas and are frequently strongly related to land degradation processes. Satellite technologies provide systematic and periodical multitemporal observations that can be fruitfully adopted for multitask and multipurpose investigations and aims, ranging from natural and anthropogenic hazards such as land-use changes, landscape deterioration, and soil degradation in the surroundings of archaeological sites (Fig. 3.7) and geoparks (Fig. 3.8).

3.2.3 Landscape Degradation: Coastal Erosion

Coastal zones are under threat from both natural and anthropogenic activities linked to the unsustainable use and overexploitation of resources. At present, more than 70% of the world's beaches are affected by coastal erosion, today considered as a serious hazard for many countries including those in Europe. The use of multitemporal, multisensory satellite data from high- and moderate-resolution sensors can support the monitoring and assessment of shoreline variations as well as analysis of water temperature, salinity, and pollution, along with other potential threats to our coasts. Assessments of shoreline changes and coastal monitoring are needed not only to predict events (such as floods) that may adversely affect environment, human health, and archaeological sites and built heritage but even to set up mitigation strategies.

Figure 3.9 shows the use of different data for the monitoring of shoreline variations close to the Metaponto archaeological area. The use of multitemporal analysis (1950, 1961, 2004, 2013) enabled estimating the changes of the Ionian coast, which from the middle of the twentieth century was characterized by alternating phases of growth and regression. The latter has prevailed since the early 1960s and continues today with varying rates of erosion.

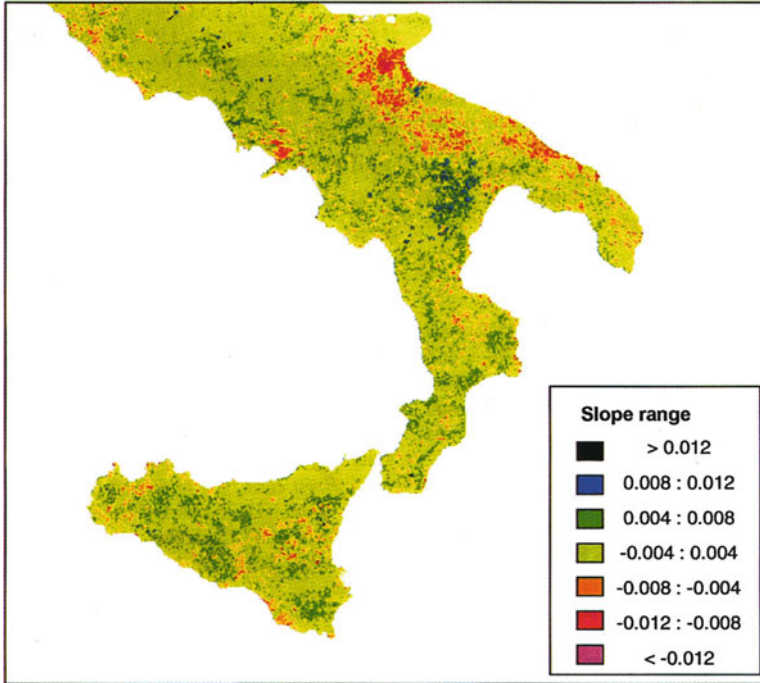


Fig. 3.6 Land degradation based on satellite data obtained for the south of Italy using a time series of AVHRR data

3.2.4 *Landscape Degradation: Urban Sprawl*

Urban sprawl indicates the expansion of urban areas generally referring to an uncontrolled and massive urbanization process, considered today as one of the most important transformations of our planet and considered now a global concern.

Even if the phenomenon is particularly dramatic in developing countries, unfortunately continuing low-density sprawl is also observed in industrialized countries. This sprawl not only adversely impacts environments with significant loss of prime agricultural lands and negative effects on carbon emissions and energy use, but also frequently impacts heritage sites and even UNESCO sites, as in the case of Giza in Egypt (Fig. 3.10), Pachacamac (see Fig. 3.11), and Chan Chan in Peru.

3.2.5 *Landscape Degradation: Pollution*

Assessment of air pollution has been performed by different means over the years, and recently the use of satellite data for detecting and monitoring atmospheric

Fig. 3.7 Satellite-based identification of fragile areas surrounding the archaeological park of Metaponto



pollution has received considerable attention, especially for application in industrial and urban areas (Hadjimitsis et al. 2002). Methods based on satellite data (such as Landsat TM, SPOT MODIS images) are focused on the estimation of aerosol optical thickness (AOT), which is a measure of aerosol loading in the atmosphere and therefore is considered as the main significant parameter of the presence or absence of atmospheric pollutants. A higher AOT value expresses the degree to which aerosols prevent the transmission of light; therefore, higher columnar of aerosol loading means lower visibility and higher aerosol concentration (Wang and Christopher 2003). AOT has been used as an indicative parameter for assessing air pollution close to cultural heritage sites.

Several state-of-the-art aerosol retrieval techniques provide aerosol properties on a global scale, as, for example, products from the moderate resolution imaging spectroradiometer (MODIS) on board the Earth Observing System (EOS) Terra and Aqua satellites (King et al. 1999). MODIS measures the total solar radiance scattered by the atmosphere as well as the sunlight reflected by the Earth's surface and attenuated by atmospheric transmission. Therefore, MODIS offers useful data for optical thickness (Tang et al. 2004).

Nevertheless, the spatial resolution of the current aerosol optical thickness (AOT) products from MODIS (available free of charge from the NASA website) is 10 km. This product is suitable for global research, but it faces difficulties in local area research, especially in urban areas. However, new aerosol retrieval algorithms for

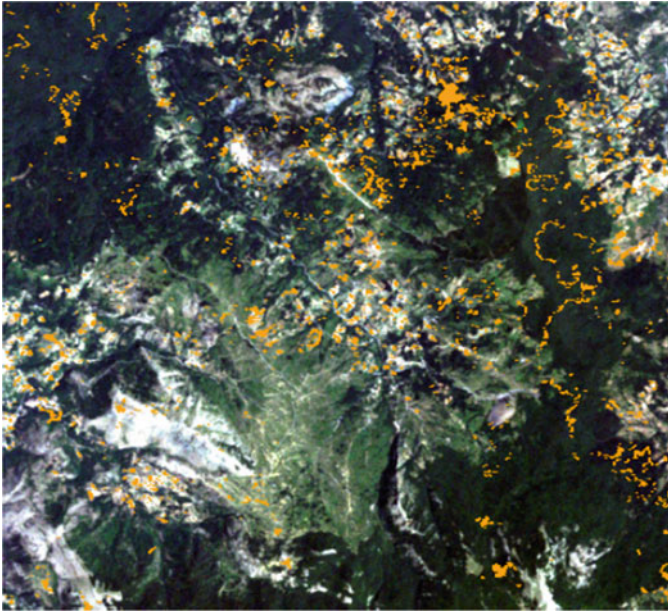


Fig. 3.8 Pollino National Park inside the Geopark UNESCO since 2016: negative anomalies (fragile areas)

the (MODIS) 500-m resolution data (see, for example, Dabin et al. 2010) have been developed to retrieve aerosol properties over land, which helps with addressing the aerosol climatic issues at a local or urban scale.

Over the years, several algorithms for determining aerosol optical thickness have been developed. For example, Kaufman et al. (1990) used the radiance difference recorded between a clear and a hazy day for land and water dark targets. Sifakis and Deschamps (1992) calculated the aerosol optical depth by using SPOT images and exploiting the difference between one reference image (acquired under clear atmospheric conditions) and a polluted image. Their method was based on the fact that, after correction of solar and observation angle variations, the remaining deviation of apparent radiances is mainly caused by pollutants.

Retalis (1998) and Retalis et al. (1999) estimated air pollution in the urban areas of Athens by using the Landsat TM band 1 and correlating the aerosol optical thickness with the acquired air pollutants.

Hadjimitsis and Clayton (2009) developed a method combining the darkest object subtraction (DOS) principle and the radiative transfer equations to evaluate the AOT value for Landsat TM bands 1 and 2. Hadjimitsis (2009) developed a method to determine the aerosol optical thickness through application of the contrast tool (maximum contrast value), radiative transfer calculations, and the “tracking” of the suitable darkest pixel in the scene for Landsat, SPOT, and high-resolution imagery such as IKONOS and Quickbird.

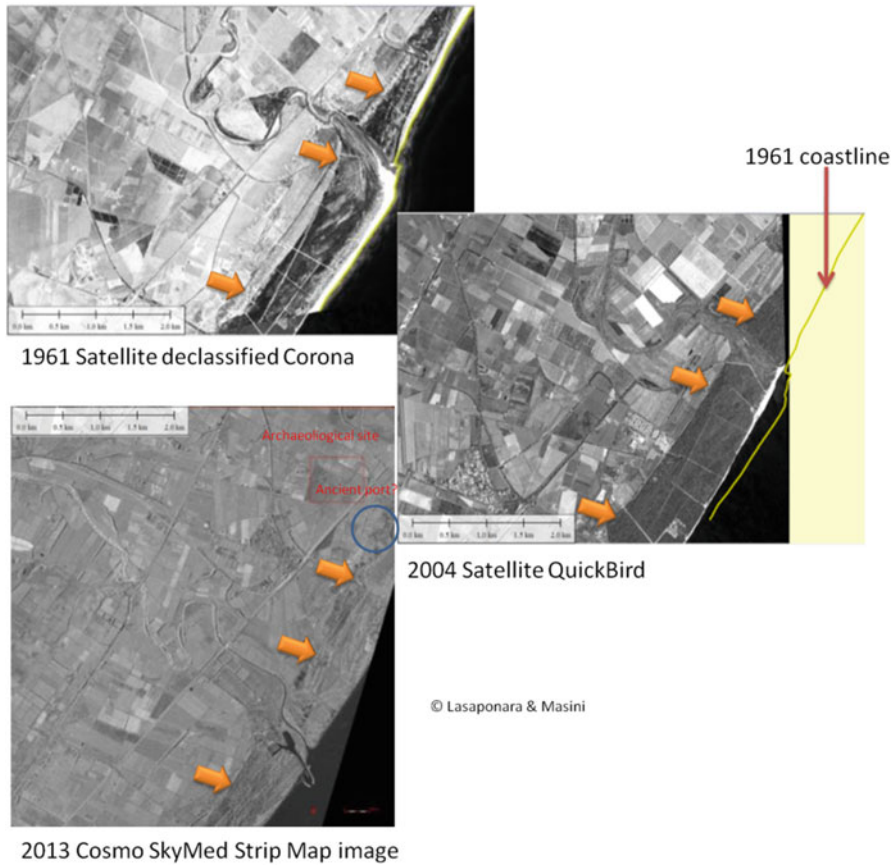


Fig. 3.9 Change detection of Ionian coastline near the ancient Metapontum (see red box(?), bottom left) by using different remote sensing data: Corona (1961), QuickBird (2004), and Cosmo SkyMed Strip Map (2013). The orange arrows denote the possible coastline in ancient times (Greek/Roman) when in Metapontum there was a port (indicated with blue circle, bottom left)

The future availability of data from the Sentinel-5 precursor (to be launched in 2017) will assure measurements of ozone, NO₂, SO₂, CH₄, CO, and aerosols. It will bridge the gap between Envisat/EOS Aura and Sentinel-5 (the latter expected to be launched in 2020). It will provide measurements of elements of atmospheric chemistry at high temporal and spatial resolution.

The availability of systematic measurements of the main atmospheric pollutants will promptly provide estimation of their impact on the natural and cultural heritage, on the basis of proxy ad hoc defined for the specific purposes. Moreover, this will address the current lack of information from in situ measurements and the strong limits of their static spatialization that today affect these analyses.

In past decades, awareness related to the impact of pollution on cultural heritage has increased as well as attention to the interaction between microclimate (in particular, moisture) and pollutants on indoor and outdoor heritage. As is well



Fig. 3.10 Urban aggression near the Giza pyramids (WorldView2 true color image)

known, cultural heritage, with particular reference to architecture and built heritage, is constantly exposed to strong fluctuations (diurnal, seasonal, decadal) of meteorological parameters that can strongly accelerate the degradation mechanisms. To understand well this phenomenon, it is important to perform systematic monitoring of meteorological parameters and their fluctuations along with their interaction with atmospheric pollutants, at least in the most precious and vulnerable areas. Moisture and temperature fluctuations negatively impact not only vegetation but also have an important role in the degradation phenomena of buildings and artifacts. In particular, it should be considered that variations in temperatures induce material expansions, which in turn cause strain between surfaces and underlying structures. It must be considered that cyclic variations tend to damage the materials, and the faster the cycles the greater the damage.

Therefore, it is quite important to have information related to daily cycles of temperatures, because the shorter variations impact the material more significantly than longer as, for example, higher seasonal variations.

Moreover, moisture content has a strong influence on the material and artifacts decay process because the negative impacts are activated in different ways. In the presence of pollutants, humidity favors chemical reactions that alter stone material as in the case of the transformation of calcareous rocks in gypsum in the presence of SO_2 (the so-called black crust)¹ (see Fig. 3.12).

¹It is the result of the sulfation process that is the transformation of calcium carbonate into calcium sulfate dihydrate.

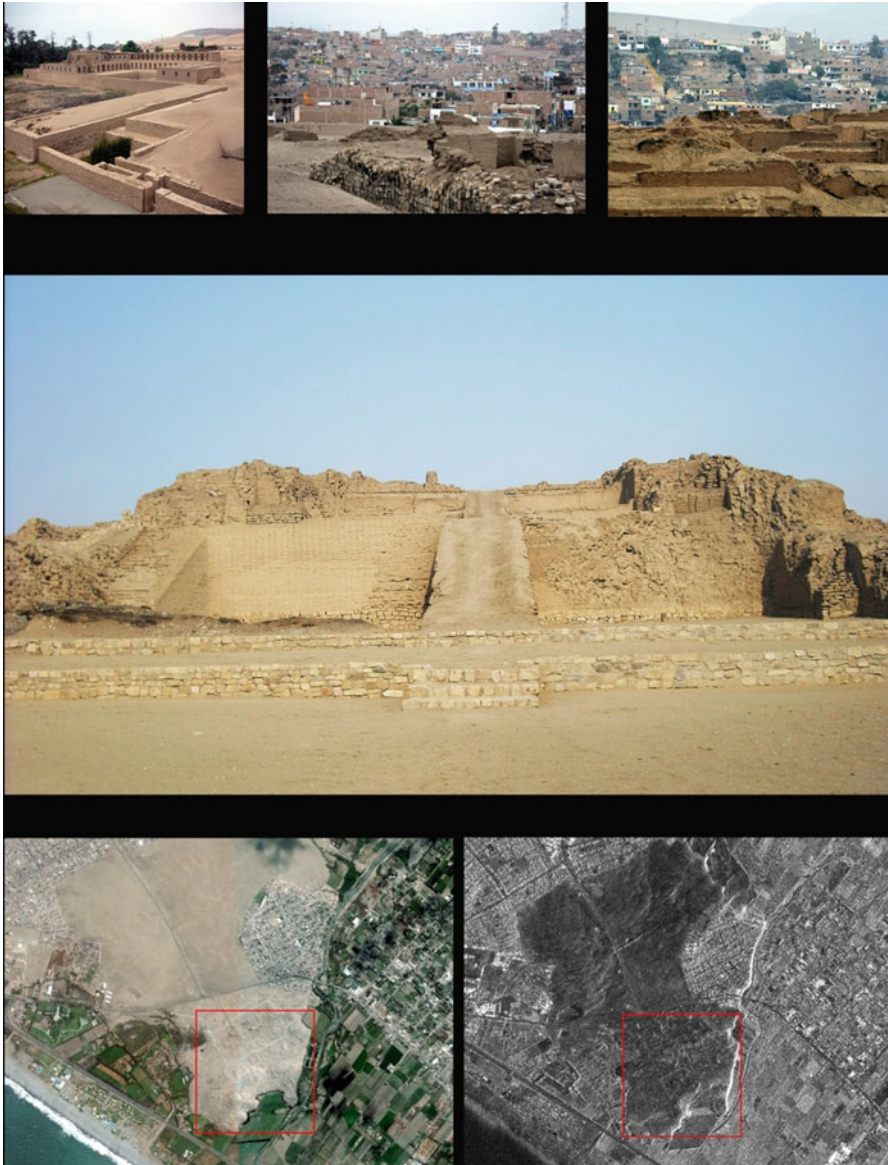


Fig. 3.11 Urban sprawl around the archaeological site of Pachacamac near Lima in Peru. *Top*, from *left to right*: details of Acclahuasi, other ruins, and the building of the modern Pachacamac very close to the archaeological site. *Middle*: detail of a pyramid with ramp. *Bottom*: optical and SAR satellite image of Pachacamac including the archaeological site (denoted by red box)

Fig. 3.12 Historical center of Dubrovnik: molded frame affected by the black crust



Fig. 3.13 Historical center of La Valletta: calcarenite blocks affected by alveolarization



Water acts in synergy with temperature: water temperature-induced changes in the quantity of water that can be absorbed. As a consequence, variation in temperature and increasing or decreasing of water absorbed by material cause expansion and contractions that can seriously damage material and artifacts.

In porous rocks, as, for example, calcarenite, alveolarization is particularly relevant. As practical examples we can consider the UNESCO site of Sassi and the Park of the Rupestrian Churches of Matera, the Baroque town of Lecce, the castle and historical palaces in La Valletta (also exposed to marine aerosol) where the evaporation process causes an increasing concentration of dissolved salts (see Fig. 3.13).

This information can be obtained using free-of-charge satellite data provided by MODIS (Figs. 3.14 and 3.15) and TM time series.

Moreover, it is important to consider that pollutants also affect the conservation of the material and strongly accelerate and increase the decay processes. The

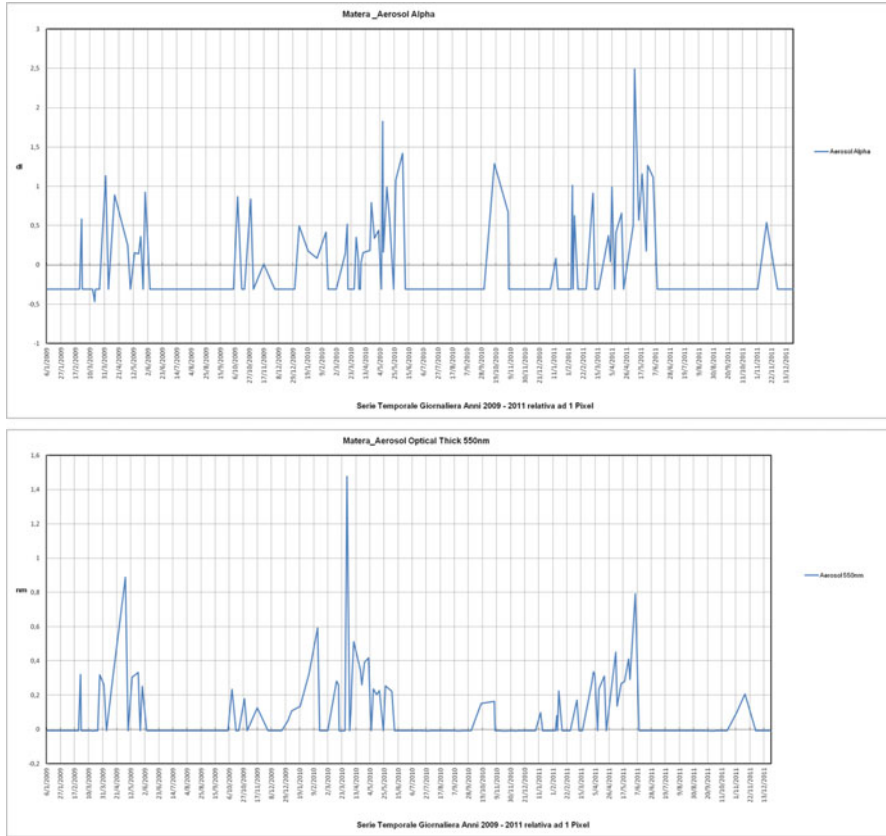


Fig. 3.14 MODIS-derived estimation of aerosol content obtained from 2009 to 2011 for the UNESCO site of Sassi Matera

state of the conservation of monuments and artifact depends on the quantity and quality of the pollutants as well as on their interaction with moisture and rain; for example, heavy showers wash away pollutants whereas a light drizzle activates the pollutants without removing them. Moreover, the frequency and the duration of humidification as well the typology of materials, their roughness, porosity, and intrinsic characteristics determine the specific decay characteristics as well as their dynamics and local effects. Therefore, to mitigate these critical conditions, knowledge of pollutants present in the atmosphere is important along with their effect on the specific materials of both indoor and outdoor heritage.

For these purposes, the satellite can provide systematic global monitoring tools at different temporal and spatial scales using different data sources, such as MODIS, Landsat TM, and Sentinel 2 time series.

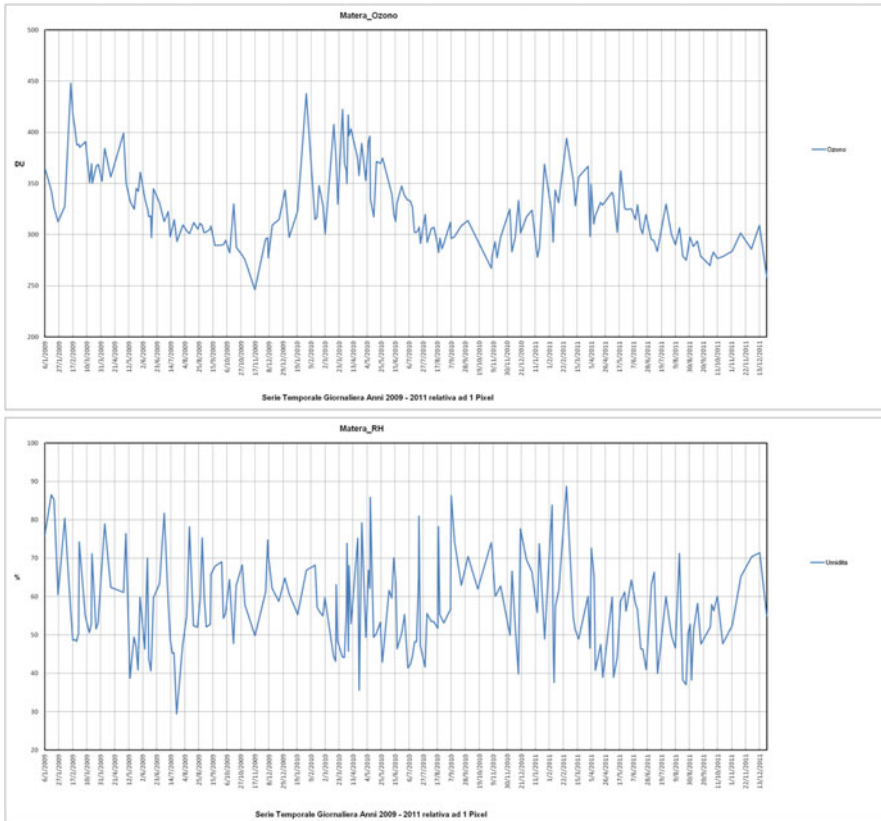


Fig. 3.15 MODIS-derived estimation of ozone and air moisture content obtained from MODIS data from 2009 to 2011 for the UNESCO site of Matera

3.3 Climate Change

Climate change during the next 100 years will likely have a range of direct and indirect effects on both natural and material environments, including the historic built environment. Important changes will include alterations in temperature, precipitation, extreme climatic events, soil conditions, groundwater, and sea level. Some processes of building decay will be accelerated or worsened by climate change whereas others will be mitigated. The impacts on individual processes can be described by linking meteorological parameters to the response of material surfaces of archaeological and historic structures, and this step is critical:

- To determine the meteorological parameters and changes most critical to the built cultural heritage
- To develop mitigation and adaptation strategies for historic buildings, sites, monuments, and materials that are likely to be most affected by climate change

As a whole, and even suggested by UNESCO, indicators can be used to complement direct monitoring or as an alternative where monitoring is not available. Table 3.1 lists the indicators recommended by UNESCO for assessing the impact of climate change on our heritage.

Scientific understanding of traditional materials and assemblies is the foundation of sustainable management of World Heritage sites in a changing climate, including chloride loading, high summer temperatures, and prolonged rainfall. The latter is often the main cause of weathering also in a desert environment as in the case of the Great Sphinx at Giza (Fig. 3.16), strongly weathered by heavy rain, probably caused by a climate change, occurred during the 4th Dynasty. Information based on cross-field monitoring must be sensitive to the scale and time of problems and guidance must be designed accordingly.

Not only should extreme events be documented but also short cycles of change that together can make significant changes to cultural heritage. Records of short cycle changes will gradually expand the notion of climate change impact on cultural heritage and enrich understanding of this phenomenon.

3.4 Space Assessment and Monitoring of Ground Displacements, Landslide, and Floods

In recent years, Spaceborne differential interferometric synthetic aperture radar (DInSAR) techniques have demonstrated their potential as land deformation measurement and ground displacements, and as such they are of great interest as possible operational tools for civil protection institutions needed to address landslide risk.

DInSAR techniques date back to 1989 when L-band SEASAT SAR data were first exploited to this aim as described in (Gabriel et al. 1989). For a general review of SAR interferometry, see Rosen et al. (2000). In the last few years, the capability of interferometric techniques has been considerably improved by using persistent scatterer interferometry (PSI) techniques based on large stacks of SAR images acquired over the same area, instead of the classical two images. PSI techniques were first published in the article by Ferretti et al. (2000). A general review of DInSAR can be found in Crosetto et al. (2005). An extensive list of successful examples is provided in Rosen et al. (2000). The significant advances of the DInSAR techniques have made them quantitative geodetic tools for deformation monitoring, rather than simple qualitative tools. A specific review of PSI applications in urban areas is provided in Crosetto et al. (2010).

Nevertheless, it is important to highlight that today the available DInSAR techniques are still not universal and robust because of two main intrinsic limitations: (i) coherence loss (or lack of persistent scatterers, PS) and (ii) the need to handle phase ambiguities (or wrapped phases). More information on the limitations of the DInSAR techniques is given by Crosetto et al. (2010).

Table 3.1 Impacts matrix, namely indicators defined and recommended by UNESCO for assessing main climate change impact on the heritage

Climate indicator	Climate change risk	Physical, social, and cultural impacts on cultural heritage
Atmospheric moisture change	Flooding (sea, river)	pH changes to buried archaeological evidence
	Intense rainfall	Loss of stratigraphic integrity because of cracking and heaving from changes in sediment moisture
	Changes in water table levels	Data loss preserved in waterlogged/anaerobic/anoxic conditions
	Changes in soil chemistry	Eutrophication accelerating microbial decomposition of organics
	Groundwater changes	Physical changes to porous building materials and finishes caused by rising damp
	Changes in humidity cycles	Damage caused by faulty or inadequate water disposal systems; historic rainwater goods not capable of handling heavy rain and often difficult to access, maintain, and adjust
	Increase in time of wetness	Crystallization and dissolution of salts caused by wetting and drying affecting standing structures, archaeology, wall paintings, frescos, and other decorated surfaces
	Sea salt chlorides	Erosion of inorganic and organic materials by flood waters Biological attack on organic materials by insects, molds, fungi, invasive species such as termites Subsoil instability, ground heave, and subsidence Relative humidity cycles/shock causing splitting, cracking, flaking and dusting of materials and surfaces Corrosion of metals Other combined effects, e.g., increase in moisture combined with fertilizers and pesticides
Temperature change	Diurnal, seasonal, extreme events (heat waves, snow loading)	Deterioration of facades by thermal stress Freeze–thaw/frost damage Damage inside brick, stone, ceramics that has become wet and frozen within material before drying
	Changes in freeze–thaw and ice storms, and increase in wet frost	Biochemical deterioration Changes in “fitness for purpose” of some structures. For example overheating of the interior of buildings can lead to inappropriate alterations to the historic fabric by the introduction of engineered solutions Inappropriate adaptation to allow structures to remain in use

(continued)

Table 3.1 (continued)

Climate indicator	Climate change risk	Physical, social, and cultural impacts on cultural heritage
Sea level rises	Coastal flooding	Coastal erosion/loss Intermittent introduction of large masses of “strange” water to the site, which may disturb the metastable equilibrium between artifacts and soil Permanent submersion of low-lying areas
	Seawater incursion	Population migration Disruption of communities Loss of rituals and breakdown of social interactions
Wind	Wind-driven rain	Penetrative moisture into porous cultural heritage materials
	Wind-transported salt	Static and dynamic loading of historic or archaeological structures
	Wind-driven sand	Structural damage and collapse
	Winds, gusts and changes in direction	Deterioration of surfaces by erosion
Desertification	Drought	Erosion
	Heat waves	Salt weathering
	Fall in water table	Impact on health of population Abandonment and collapse Loss of cultural memory
Climate and pollution acting together	pH precipitation	Stone recession by dissolution of carbonates Blackening of materials
	Changes in deposition of pollutants	Corrosion of metals Influence of biocolonialization
Climate and biological effects	Proliferation of invasive species	Collapse of structural timber and timber finishes
	Spread of existing and new species of insects (e.g. termites)	Reduction in availability of native species for repair and maintenance of buildings
	Increase in mold growth	Changes in the natural heritage values of cultural heritage sites
	Changes to lichen colonies on buildings	Changes in appearance of landscapes
	Decline of original plant materials	Transformation of communities Changes in the livelihood of traditional settlements Changes in family structures as sources of livelihoods become more dispersed and distant



Fig. 3.16 The Great Sphinx at Giza. Its conservation is threatened by strong weathering processes

The most important limitation of DInSAR is coherence loss, which means that the measure deformation is only over the available coherent pixels and PSs. Statistical analysis provides the estimation for the whole image data. The second limitation is related to the ambiguous nature of the DInSAR observations: it suffers severe limitations in the capability to measure fast deformation phenomena.

To overcome these drawbacks, several DInSAR data analysis procedures have been devised in the last 20 years ranging from a very simple approach, such as the standard DInSAR configuration (based on a single interferogram computed from a pair of complex SAR images) to PSI techniques, based on the use of redundant SAR data and quite refined estimation procedures.

Recently, Crosetto et al. (2011) proposed different complementary DInSAR methods, used together to obtain improved performance and flexibility. In particular, Crosetto et al. (2011) proposed the joint use of the (i) standard DInSAR analysis [see, for example, Biescas et al. (2007) and Crosetto et al. (2002)]; (ii) PSI analysis over small areas [see, for example, Biescas et al. (2007), Monserrat et al. (2011)]; (iii) full PSI analysis with linear deformation model [see, for example, Berardino et al. (2002) and Lanari et al. (2004)]; and (iv) full PSI analysis with free deformation model (see Crosetto et al. 2011). During the past decade, the listed methodologies were implemented, tested, and validated using different types of spaceborne SAR data acquired by the following sensors: ERS-1 (C-band), ERS-2 (C-band), ASAR-Envisat (C-band), TerraSAR-X (X-band), and Cosmo SkyMed (X-band), also for detecting deformation at a single-building scale from the perspective of conservators. This analysis has been done for the historical center of Rome by Cigna et al. (2014) by processing X-band COSMO-SkyMed StripMap HIMAGE time series of 2 years (2011–2013) and for the archaeological park of Pompeii

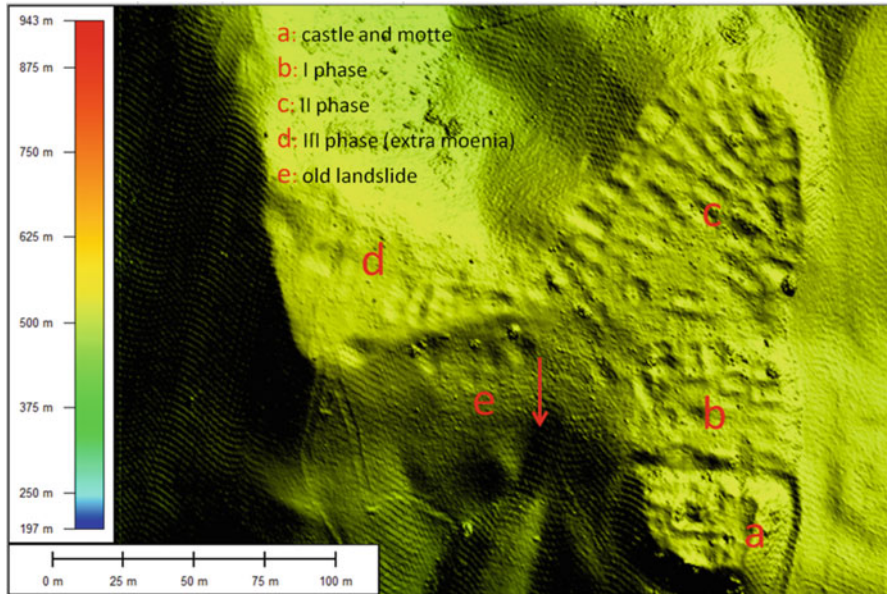


Fig. 3.17 Medieval village in Southern Italy: the DTM derived from LiDAR survey allowed not only reconstructing the historical urban phases (a, b, c, d) but also detecting an old landslide (e) that likely contributed to the abandonment of the settlement

by CNR-IREA (Bonano et al. 2016, in this volume) applying the SBAS-DInSAR technique to two C- and X-band satellite datasets, collected during the 1993–2015 time interval from the “first” (ERS and ENVISAT) and the “second” (CSK) SAR sensor generations

Landslide monitoring can be successfully approached by using drones, high-resolution optical satellite data, and LIDAR. Figure 3.17 shows the evidence of a landslide close to a medieval village in Basilicata as obtained by a survey based on LIDAR, which probably was one of the causes of the abandonment of this village that occurred in the fifteenth century (Lasaponara and Masini 2009).

3.5 Archaeological Looting and Vandalism

Looting of archaeological sites and ancient artifacts has a long history. Over the centuries looting has usually been a part of war; starting at least since 333 BC (<http://www.smithsonianmag.com/making-a-difference/looting-iraq-16813540/>) during the war of Alexander the Great against King Darius III.

In past centuries, clandestine excavation activities have been mainly linked to illicit trade of antiquities. To contend with this phenomenon, in many countries

repressive measures were adopted along with restrictive laws to impose the returning of objects derived from clandestine excavations or theft to their own countries

In 1956 the General Conference of the United Nations Educational, Scientific and Cultural Organization recommended all the Member States to take “all necessary measures to prevent clandestine excavations and damage to monuments and also to prevent the export of objects thus obtained” (UNESCO 1956).” In 1970, UNESCO promulgated the Convention on the Means of Prohibiting and Preventing the Illicit Import, Export and Transfer of Ownership of Cultural Property (UNESCO 1970), also including (in UNESCO 2001) underwater archaeology. Additional actions have been adopted recently to condemn and contrast the looting and illegal excavations that have exponentially increased in the Middle East since the beginning of the conflict in Syria. The United Nations Security Council, on 12 February 2015, adopted Resolution 2199 that convicts the destruction of cultural heritage and adopts legally binding measures to counter illicit trafficking of antiquities and cultural objects.

Despite these efforts, looting and artifact trafficking remain a pervasive broad-based phenomenon through the world, and important cultural property has disappeared from many countries, as revealed from the survey conducted by Proulx (2013). Therefore, illegal excavations represent one of the main risk factors affecting the archaeological heritage throughout the world.

Actions oriented to preventing looting can be supported by aerial (including UAV, see Fig. 3.18) and satellite systems. Aerial surveys and the use of UAV can be limited by the extent of the areas under surveillance, whereas the use of satellites can provide reliable information useful to (i) quantify the looting phenomenon even if it is at an “industrial scale” over large areas; and (ii) set up a systematic monitoring tool also for remote areas not accessible because of war or other limiting factors.

Taking advantage of large-spatial coverage, high-spectral and sensitivity satellite remote sensing can be usefully adopted for contrasting looting. Satellite technologies offer a suitable chance to quantify and analyze this phenomenon, especially in those countries, from South America to the Middle East, where the surveillance on site is not very effective and is time consuming or impractical as the result of military or political restrictions.

Recent applications, mainly focused in Peru (Lasaponara et al. 2012, 2014, Lasaponara and Masini 2010, Contreras 2010) and in areas of ongoing conflicts such as Iraq and Iran (Casana and Panahipour 2014; Stone 2008; Van Ess et al. 2006), have shown that VHR satellite imagery is of great help in the remote surveying of archaeological heritage and in monitoring of the damage from looting.

In particular, focusing on Peru, Contreras (2010) used remote sensing imagery from aerial and space platforms to assess looting damage via photointerpretation in the Virù valley. From the methodological perspective, Lasaponara and Masini (2010) provided a significant contribution by devising a pioneering semiautomatic looting classification, which was applied to Cahuachi just in Peru. To enhance the circular holes that typically characterized the spatial patterns of looting, they adopted statistical analysis based on local indices of spatial autocorrelation (LISA). The highly satisfactory results, further validated by ground survey (Lasaponara et al.

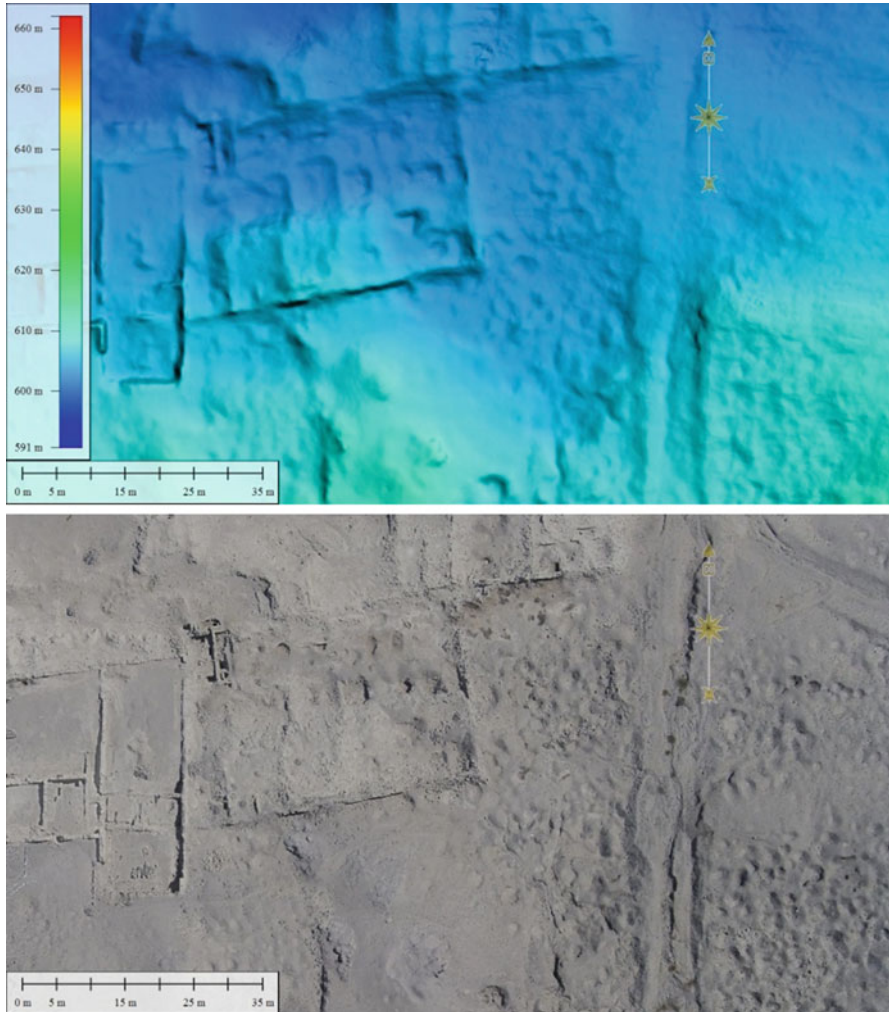


Fig. 3.18 Inca site of Paredones near Nasca (Southern Peru). The DEM and the orthophoto derived by aerial images taken from drone evidence the intense looting activity

2012), encouraged the authors to further improve the methodological approach. A fully automatic procedure (Lasaponara et al. 2014) was developed and tested in one of the most ancient archaeological sites in Southern America, Ventarrón in Northern Peru.

Focusing on the Middle East and areas of ongoing conflicts, Van Ess et al. (2006) compared prewar and postwar IKONOS images to identify looted areas near Uruk-Warka, situated 300 km south of Baghdad. They located looting activities by using supervised classification methods. Stone (2008, 2015) estimated the extent of the damaged areas and the chronology of looting by using multivariate QuickBird

images. Casana and Panahipour (2014) worked for several years, in the framework of a NASA-funded research project, to develop a comprehensive archaeological site database that includes 15,000 sites in Syria and surrounding regions.

3.6 Conclusions

Space technologies offer great availability of active and passive data that have a multitude of applications in the detection, documentation, monitoring, and management of natural and cultural sites. Satellite imagery can fruitfully cope with the need to providing documentation by visualization of natural and cultural heritage that improves support and data which can be promptly integrated with ancillary information and any other data sources. In particular, the high resolution of satellite images (currently up to 30 cm) enables deriving accurate maps of the current and ongoing status by analyzing changes and human-induced activities and assessing their impact at landscape down to building level. Moreover, by exploiting multitemporal satellite images or time series, remote sensing enables identifying emerging threats to the heritage sites, setting up mitigation strategies, and assessing if conservation measurements are being effective.

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