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Satellite and ground-based radar interferometry for detection and monitoring of structural instability in archaeological sites

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Sustainable and cost-effective management strategies of huge archaeological areas with high concentration of monuments require accurate identification of the most critical sectors and structures, on which appropriate restoration interventions should be focused. Integrated approaches combining on-site investigations and conventional monitoring systems can also benefit from the employment of advanced remote sensing technologies specifically suitable for the detection of structural and ground motions affecting archaeological heritage. In the last years Synthetic Aperture Radar Interferometry (InSAR) techniques have been increasingly used to measure terrain motions due to both natural and human-induced processes with different kinematics, demonstrating their capabilities for non-invasive diagnosis and conservation of cultural heritage. Here we discuss the results from the highly detailed surveys performed at different scales on archaeological sites within the urban area of Rome (Italy), in the framework of co-operation with the Commissioner for the archaeological areas of Rome and Ancient Ostia, Italian Ministry of Cultural Heritage and Activities. The above mentioned surveys, based on both satellite and ground-based radar monitoring campaigns, successfully contributed to the analysis of spatial and temporal evolution of past and recent structural and ground motions on Palatino Hill and Roman Forum. For these areas a long history of instability events is recorded; the severest collapse occurred in November 2005 and damaged the Farnesian Walls in the NE sector of the hill. Such events are not so rare in archaeological contexts where the geological substratum is prone to instability (e.g., block toppling, landsliding, cavities collapse) and affected by groundwater seepage and surface water infiltration; weathering and decay processes can also compromise the structures, formerly subterranean and currently completely exposed, disaggregating the ancient mortars and weakening the masonry. Combining specific capabilities of satellite and ground-based InSAR technologies, a new integrated methodology was implemented, performing a monitoring campaign, respectively, at 'archaeological site scale' and 'single monument scale'. Persistent Scatterer Interferometry (PSI) was exploited to both reconstruct past deformation occurred in 1992-2000 (ERS1/2 data) and measure the ongoing deformation (2003-2009; RADARSAT-1 data) with millimetre accuracy and monthly data acquisition frequency. Complementarily, a real-time structural monitoring by means of Ground-Based InSAR (GB-InSAR) instrumentation was focused on the monuments most affected by past instability events, continuously controlling their stability with high sampling frequency (up to 1 image every 6 minutes) since April 2009. Time-series analysis of long temporal radar satellite data stacks and interpretation of the spatial distribution of the average annual displacement velocities highlighted localized ground motions (up to 20 mm/yr, as measured in the area of the Temple of Magna Mater along the SW slope of Palatino Hill), suggesting a strong correlation with the subterranean cavity network and local geological setting, and also contributing to the identification of the most critical sectors where programmed restorations are being currently carried out. On the other hand, GB-InSAR analysis confirmed an overall stability of the monuments during the monitoring period, allowing real-time warning in case of occurrence of differential movements recognizable within the constantly updated displacement time series. As demonstrated by the present case study, the suitability for performing multiple scale analyses makes the InSAR techniques efficient diagnostic tools to distinguish unstable sectors from the stable ones and, consequently, to provide recommendations and guidelines for planning adequate countermeasures and prevention of instability events potentially hazardous for the conservation of archaeological heritage.