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Resolving land subsidence within the Venice Lagoon by persistent scatterer SAR interferometry

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A B S T R A C T

Land subsidence is a severe geologic hazard threatening the lowlying transitional coastal areas worldwide. Monitoring land subsidence has been significantly improved over the last decade by space borne earth observation techniques based on Synthetic Aperture Radar (SAR) interferometry. Within the INLET Project, funded by Magistrato alle Acque di Venezia – Venice Water Authority (VWA) and Consorzio Venezia Nuova (CVN), we use Interferometric Point Target Analysis (IPTA) to characterize the ground displacements within the Venice Lagoon. IPTA measures the movement of backscattering point targets (PTs) at the ground surface that persistently reflect radar signals emitted by the SAR system at different passes. For this study 80 ERS-1/2 and 44 ENVISAT SAR scenes recorded from 1992 to 2005 and from 2003 to 2007, respectively, have been processed. Highly reliable displacement measurements have been detected for thousands of PTs located on the lagoon margins, along the littorals, in major and small islands, and on single structures scattered within the lagoon. On the average, land subsidence ranges from less than 1 mm/year to 5 mm/year, with some PTs that exhibit values also larger than 10 mm/year depending on both the local geologic conditions and the anthropic activities. A network of a few tens of artificial square trihedral corner reflectors (TCRs) has been established before summer 2007 in order to monitor land subsidence in the inner lagoon areas where "natural" reflectors completely lack (e.g., on the salt marshes). The first interferometric results on the TCRs appear very promising.

1. Introduction

With the stop of the aquifer overexploitation in the early 1970, the component of the Venice land subsidence due to groundwater pumping was arrested (Carbognin et al., 1977). The relative land stability of the historical center was verified by leveling surveys in 1993 (Carbognin et al., 1995, 2000; Tosi et al., 2000), and recently confirmed by the integration of different techniques (Tosi et al., 2002). In Tosi et al. (2002) a Synthetic Aperture Radar (SAR)-based method was applied for the first time in the Venice area to measure the vertical land displacements of the historical center. The analysis was carried out by the Differential Interferometric SAR (DInSAR) approach that is used in geophysical sciences since the late 1980s (Gabriel et al., 1989). With DInSAR two (or more) SAR images taken from very close orbital positions at different times are combined (interferometric processing) to exploit the phase difference of the radar signals which is related to the earth surface displacement occurring between the acquisition of the image pair, once the surface topography contribution is removed and the atmospheric disturbance mitigated (e.g., by average of a stack of interferograms). The interferogram phase noise ("decorrelation") restricts the DInSAR use. Major contributions to the phase noise are the temporal and the spatial decorrelation, the former due to the temporal change of the scatterers, as is the case of densely vegetated areas, and the latter to the slightly different viewing positions (interferometric baseline) related to the orbits.

More recently, a refined approach known as Persistent Scatterer Interferometry (PSI) or Interferometric Point Target Analysis (IPTA) has been developed taking advantage from the fact that, when the dimension of a reflecting target is smaller than the image resolution cell, the coherence of the reflected radar signal is preserved irrespective of the image pair baseline (Usai and Klees, 1999; Ferretti et al., 2001; Werner et al., 2003). Consequently, more observations are available, allowing for a reduction of atmospheric disturbances. IPTA interferometric phases are thus interpreted only

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for a number of selected single pixels (“point targets”, PTs) that are coherent over long-time intervals and cover the monitored area as a sparse “natural” benchmark net. By IPTA, the interferometric SAR-based survey can be performed in rural areas as well using existing pointwise reflectors (e.g., buildings, bridges, etc.), with the requirement of a PT density larger than about 1 km^{-2}.

DInSAR and IPTA have been applied on the Veneto region within the “VENEZIA Project: Subsidence monitoring service in the Lagoon of Venice for regional administrative and water authorities” funded by European Space Agency (ESA, http://www.dup.esrin.esa.it/projects/summaryp33.asp). Land displacements have been retrieved at the regional scale and for three local areas of major interest (Venice, Chioggia, the Zennare Basin) using 59 ERS SAR data from 1992 to 2000 (Teatini et al., 2005, 2007).

The Venice Water Authority (VWA) and its concessionary Consorzio Venezia Nuova (CVN) have funded in 2006 the INLET Project. The main goals of this new research are (i) to extend the IPTA investigation at the local scale in the Venice Lagoon till 2007 using the ENVISAT satellite and (ii) establish a network of trihedral corner reflectors (TCRs) within the lagoon where no subsidence information has been retrieved to experiment the IPTA capability of detecting the movements of these “artificial” structures installed ad hoc for the subsidence monitoring. After a short description of the IPTA methodology and its peculiar application to the study area, the paper provides some representative results showing the strong capability of IPTA to monitor the land displacements in transitional coastal environments and its promising applicability on TCRs.

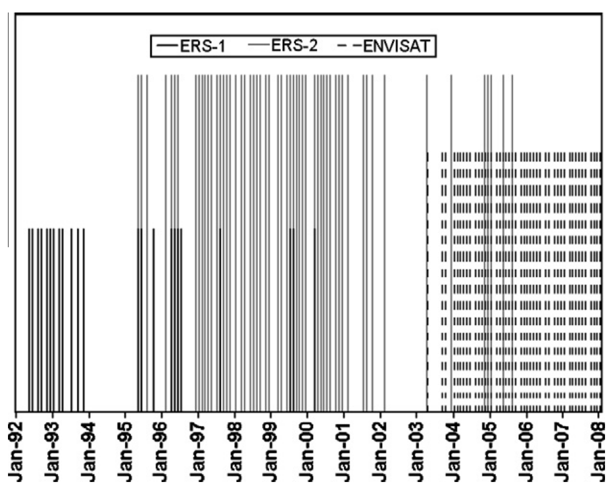

Fig. 1. SAR images from ESA satellites available on the Venice Lagoon area and used by IPTA.

2. IPTA application in the Venice coastland

2.1. Satellite data

A stack of 80 ERS-1/2 and 44 ENVISAT scenes recorded from October 10, 1992, to August 24, 2005, and from February 4, 2003, to December 12, 2007, respectively (Fig. 1), have been commercially acquired by the VWA and processed with IPTA on the whole lagoon area.

The PTs detected in the study area amount to about 90,000 and 190,000 for the ERS-1/2 and ENVISAT images, respectively (Fig. 2). The difference is related to the criteria used to select the targets on which develop the investigations. With ERS-1/2, the interferometric analysis is primarily focused on the displacement processes occurring at a large (regional) scale by using a relatively strict condition on the coherence of the PT response in order to derive only very accurate measurements. A smaller coherence threshold is used with the ENVISAT data to obtain a larger number of PTs, even if in part characterized by a more noisy displacement history, on which develop a detailed interpretation at the local scale.

For each PT, IPTA provides the time series of the land displacement along the line-of-sight between the satellite and the target, which slope is 23° with respect to the vertical direction, over the time interval of about 15 years. The SAR analysis is carried out separately for the ERS-1/2 and the ENVISAT images because of a certain difference between the frequency of the radar sensors mounted in the two satellites. A total number of 80 and 42 interferograms is computed using the images dated October 15, 1997, and December 12, 2004 for the ERS-1/2 and ENVISAT acquisitions, respectively, as central reference.

Moreover, IPTA provides the PT coordinates in the SAR reference image and in the Italian cartographic system (Gauss-Boaga, zone 2,

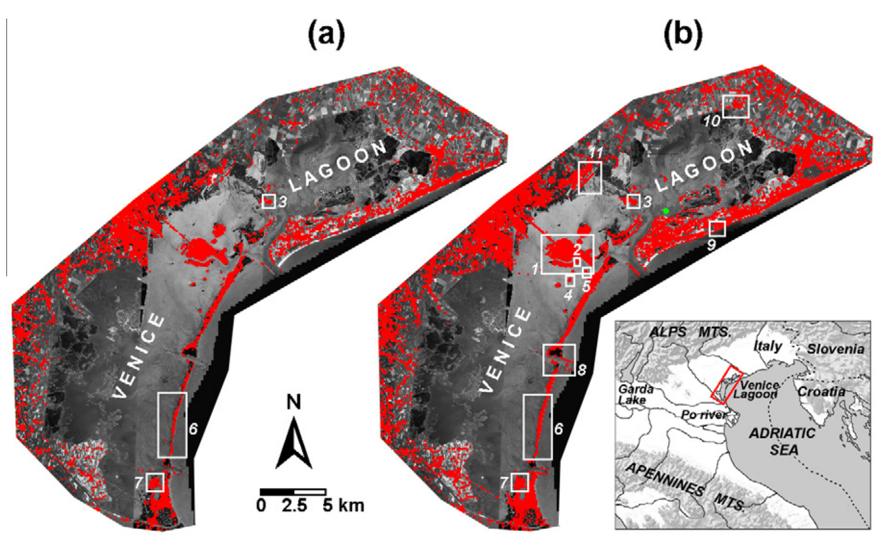

Fig. 2. Satellite image of the Venice Lagoon with the location of the natural PTs detected by IPTA from ERS (a) and ENVISAT (b) scenes. The white boxes highlight the areas where the IPTA results are presented at the local scale: (1) Venice, Fig. 4; (2) San Giorgio island, Fig. 5; (3) Burano island, (4) San Clemente, and (5) San Servolo islands, Fig. 6; (6) Cavallino littoral and (7) Chioggia, Fig. 7; (8) Malamocco inlet, Fig. 8; (9) Cavallino littoral, (10) Caposile, and (11) Marco Polo airport at Tessera, Fig. 9. The location of the artificial reflector established in the San Felice marshland, northern lagoon, is represented by a green dot in (b).