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GROUND VERTICAL MOVEMENTS IN URBAN AREAS OF THE VENETO REGION (ITALY) DETECTED BY DInSAR

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Remote-sensing techniques represent suitable tools for geological cartography and sustainable management of natural resources. Spaceborne Synthetic Aperture Radar (SAR) systems offer the possibility, through differential SAR interferometry (DInSAR), to map surface displacements at mm to cm resolution [1, 2]. Spectacular results are obtained for geophysical sciences with earthquake displacement [3], volcano deformation [4], glacier dynamics [5] and land subsidence [6, 7, 8] being mapped. With regard to land subsidence, SAR interferometry exhibits complementary characteristics to the levelling surveys, because it has the capability to map large urban areas at low cost and high spatial resolution. The high precision levelling surveys, on the other hand, are used outside of the cities and to set up a reference point for the SAR subsidence values. In the case of the south-eastern Veneto region, where till to 2000 high precision levelling surveys are available only (*i*) around the Lagoon margin and along few lines from (*ii*) Venezia to Rua di Feletto (Treviso), from (*iii*) Mestre to Padova, (*iv*) form Padova to Rovigo, and (*v*) from Chioggia to Adria (Figure 1) [9], SAR interferometry has the capability to monitor the vertical displacements of all the built-up or sparsely vegetated areas (i.e. where stable structures permit the formation of a coherent phase signal over time) not fully covered with levelling results.

DInSAR makes use of two SAR images acquired from slightly different orbit configurations and at different times to exploit the phase difference of the signals. The phase signal derived from an interferometric image pair relates both to topography and line-of-sight surface movement between the acquisitions, with atmospheric phase distortions, signal noise and inaccuracy in the orbit determination as main error sources. The basic idea of DInSAR is to subtract the topography related phase (for instance simulated from a Digital Elevation Model) from the interferogram to derive a displacement map. In this study a time series of six interferometric radar images of the European Remote Sensing Satellites ERS-1 and ERS-2 from 1993 to 2000 was used. In order to generate a single subsidence map with reduced errors, the interferometric radar images were combined. In the following, displacement in the vertical direction was assumed, the land subsidence map was transformed to the Italian cartographic system with a spatial resolution of 30 m, and the pixel corresponding to the benchmark Nodale 63 (ex 24') in Treviso (that has been already considered stable for the levelling surveys) was considered the stable reference.

The high accuracy of the 1993-2000 DInSAR survey is confirmed by a quantitative validation with the 1993-2000 levelling data. For the 87 benchmarks where values from both surveying techniques are available a zero average difference of the vertical displacement velocity is prescribed and a standard deviation of 0.9

mm/year is found; the minimum and maximum differences are –3.1 mm/year and +2.5 mm/year, respectively. From this number and previous works [7] we conclude that the accuracy of the SAR interferometric subsidence rates is on the order ±1 mm/year, which is also the expected accuracy of the levelling surveys [10].

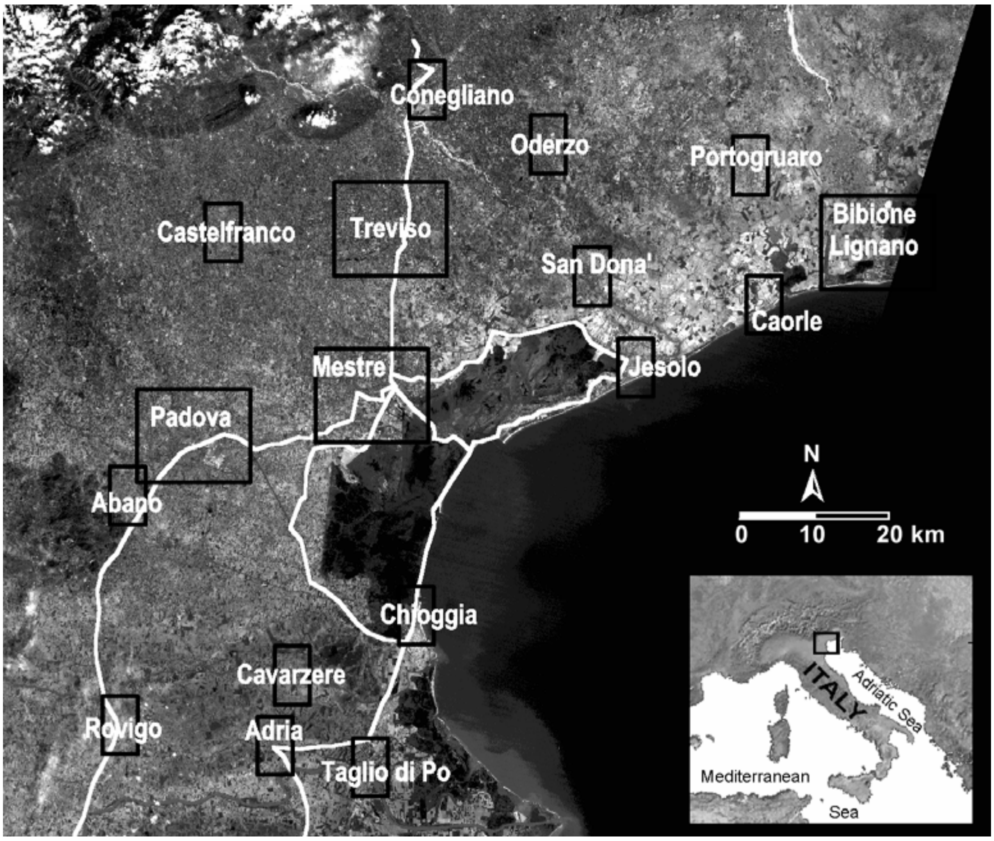

FIGURE 1. Landsat image of the study area with the trace of the leveling lines in white and the urban areas with DInSAR application in black.

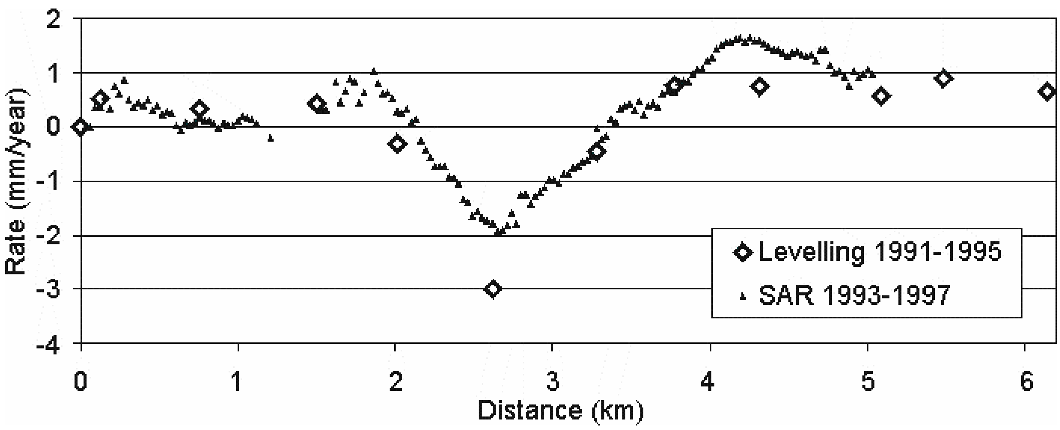

FIGURE 2. Quantitative validation of the 1993-1997 vertical displacement velocity from DInSAR with the measurements provided by 1991-1995 leveling along the line A-B of Figure 3. Leveling data courtesy of Abano Municipality and Veneto Region.

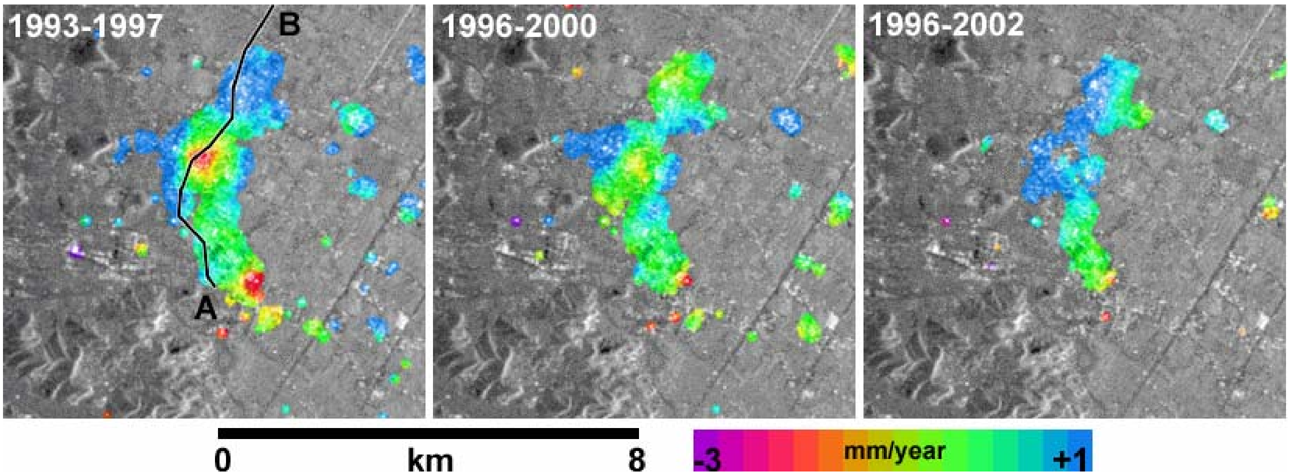

FIGURE 3. Evolution of the ground vertical velocity in Abano – Montegrotto Terme detected by DInSAR during the last decade.

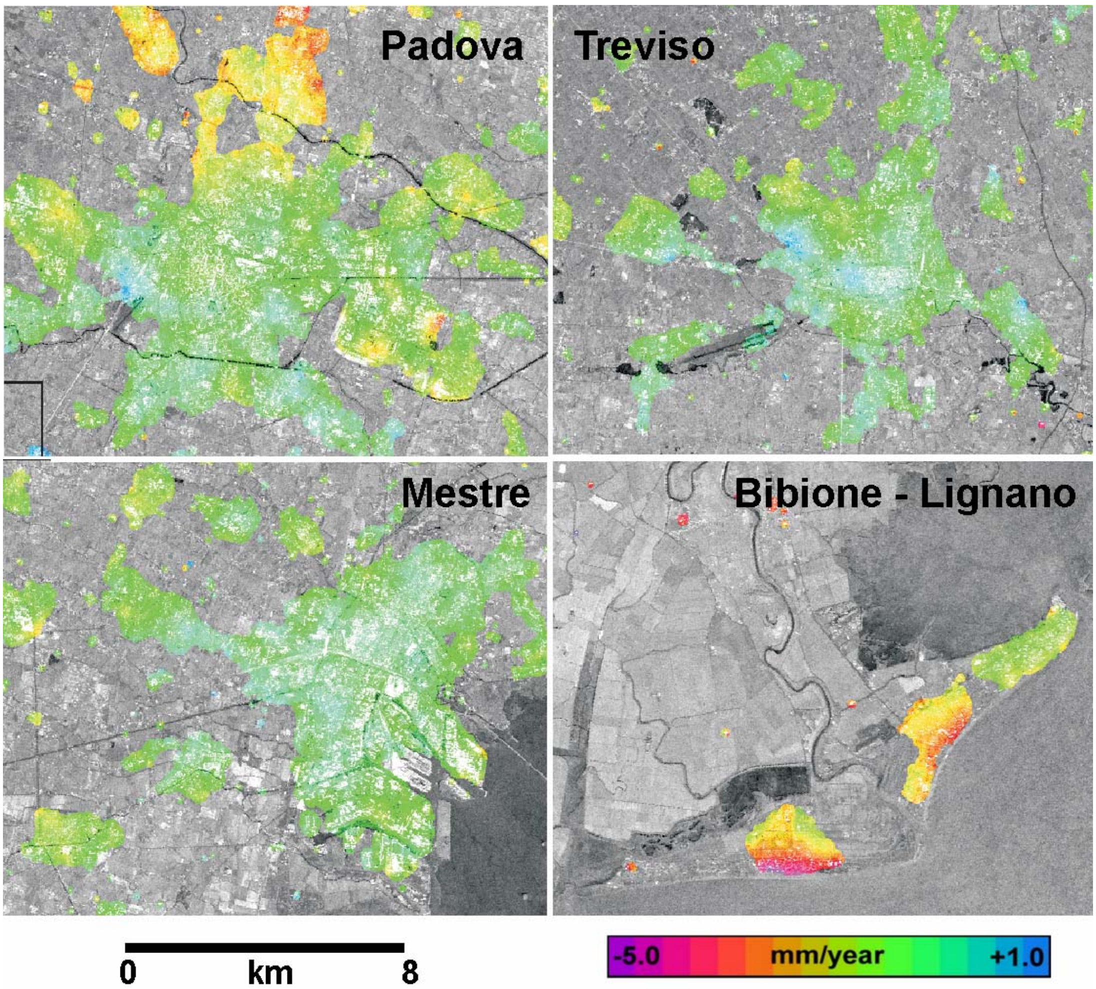

FIGURE 4. Ground vertical velocity detected by DInSAR in major urban areas of the south-eastern Veneto region for the 1993-2000 period.

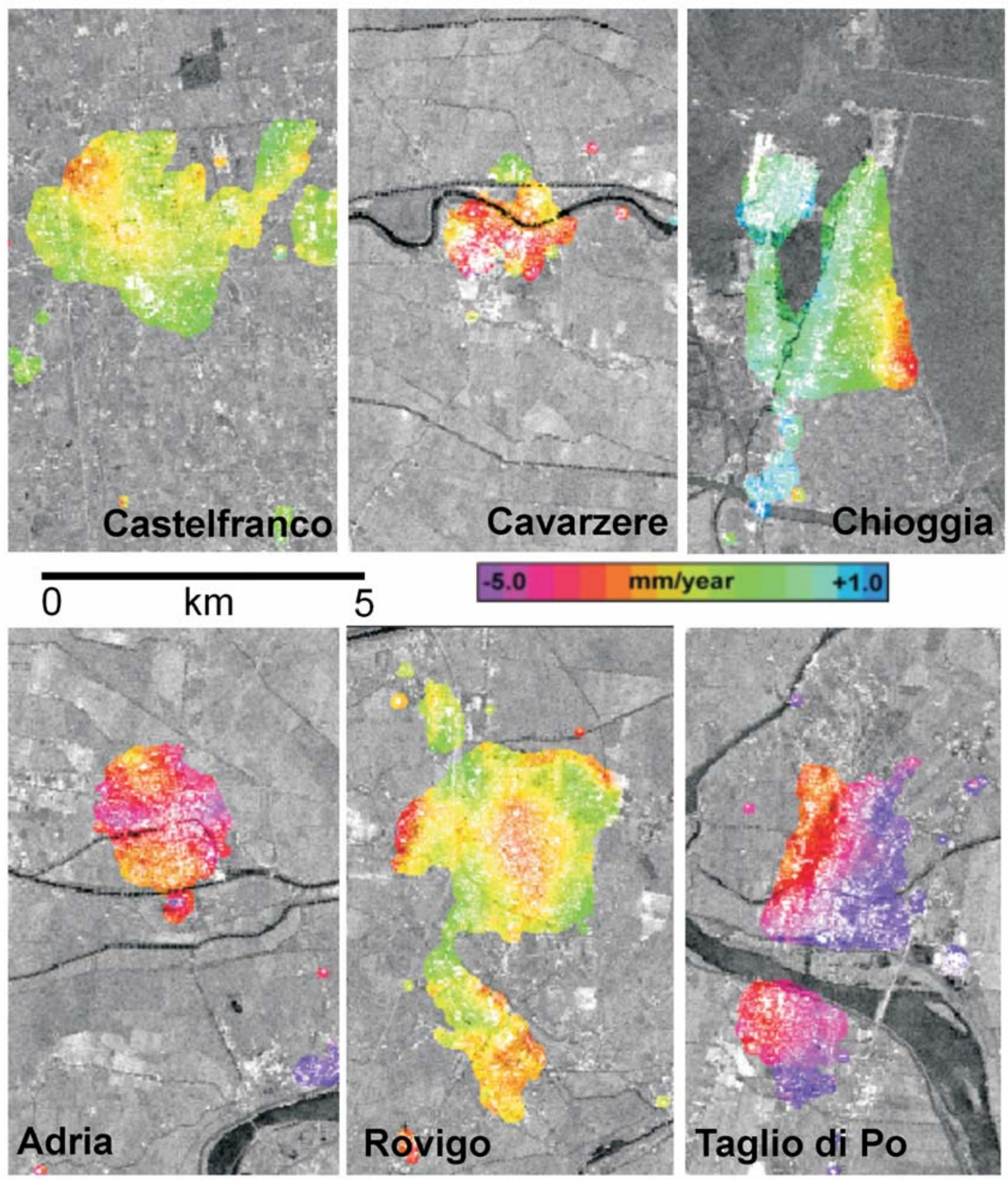

FIGURE 5. Ground vertical velocity detected by DInSAR in small urban areas of the south-eastern Veneto region for the 1993-2000 period.

Figures 2 and 3 show an example of the DInSAR capability to monitor the evolution of land subsidence in small urban area (Abano – Montegrotto Terme) where clearly appears the influence of the drastic reduction of groundwater pumping used for geothermal purpose. DInSAR results match very well the available leveling data.

DInSAR mapping in large cities such as Padova, Treviso, and Mestre is given in Figure 4. These applications indicates the potentiality of the radar satellite analysis in built-up areas characterized by a general stability, with displacement rate within the range ±1 mm/year.

DInSAR use looks very useful to perform detailed investigations in coastal areas too. Figure 4 (Bibione – Lignano), Figure 5 (Chioggia), and Figure 6 (Jesolo and Caorle) reveal the presence of a significant seaward gradient in land subsidence practically impossible to be detected by other traditional monitoring techniques like geometric leveling and DGPS. Hence, the proposed methodology provides a fundamental support for coastal management projects and environmental risk analyses.

SAR interferometry has been applied in other minor cities of the Veneto plain characterized by very different conditions form the displacement point of view. Castelfranco (Figure 5) and Conegliano (Figure 6) located close to the Alpine foothills appear quite stable; land settlement in Rovigo (Figure 5) appears very changeable with high values (2-3 mm/year) downtown and lower rate (about 1 mm/year) in the outskirts; in Cavarzere (Figure 5), and Oderzo, San Donà (Figure 6) the subsidence velocity ranges between 3 and 4 mm/year.

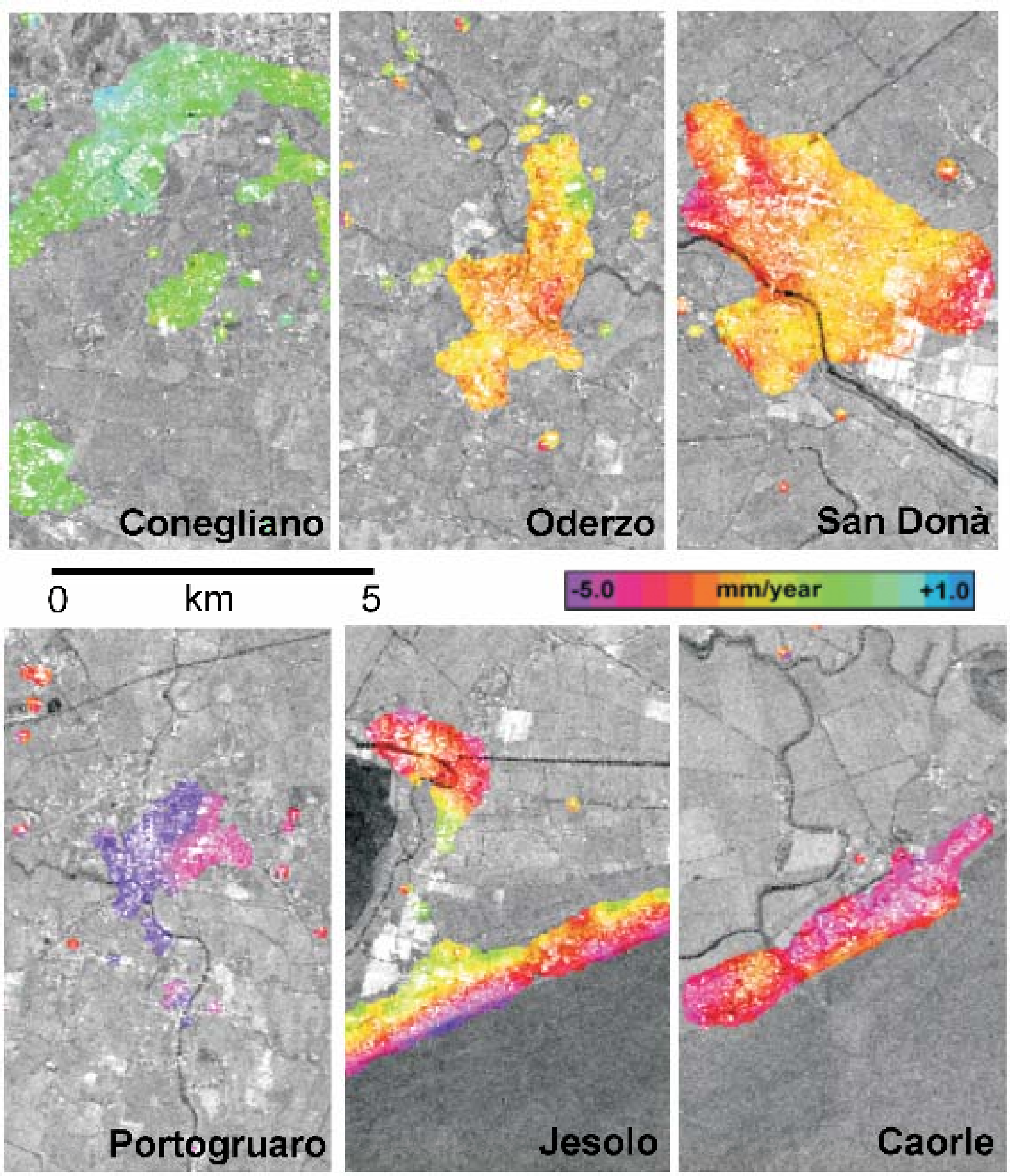

FIGURE 6. Ground vertical velocity detected by DInSAR in small urban areas of the south-eastern Veneto region for the 1993-2000 period.

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The more critical situation is found in Adria, Taglio di Po (Figure 5), and Portogruaro (Figure 6) where the sinking velocity reaches 5 mm/year in large portion of these towns.
Although in 2000 the old leveling network (Figure 1) has been extended within the framework of the ISES Project (the present overall length is about 1000 km), a detailed monitoring of several villages is impossible though leveling and DGPS. Because in these urban areas the hydrogeological risk is high due to the presence of rivers and the critical elevation, since they often lie below the mean sea level, the areally distribution of the subsidence rate has to be well known. Results shown by the present work prove that this integration in the knowledge of the subsidence process can be efficiently obtained by DInSAR. This technique represents an effective methodology for both a back-analysis during the last decade and the future monitoring in the portion of territory covered by large and small built-up areas.

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