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Present ground surface dynamics in the North Adriatic coastland

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RIASSUNTO

Dinamica attuale del suolo nella pianura costiera dell'alto Adriatico

Le livellazioni geometriche sono state nel secolo scorso l'unico metodo di rilievo altimetrico che abbia consentito di misurare con precisione l'entità della subsidenza "moderna" dell'area costiera nord adriatica. Solo alla fine degli anni 1990 è stata istallata una rete per misure GPS in differenziale (DGPS) e in continuo (CGPS). Nell'ultimo decennio inoltre, l'utilizzo del radar ad apertura sintetica (SAR) su vettori satellitari ha consentito lo sviluppo e l'affinamento dell'analisi interferometrica differenziale (InSAR) e dell'analisi interferometrica su riflettori persistenti (IPTA) che si sono dimostrati di estrema efficacia per lo studio dei movimenti verticali del suolo. Nel caso della pianura costiera Veneta, sono stati utilizzati i satelliti ERS-1/2 ed ENVISAT dell'Agenzia Spaziale Europea, rispettivamente per il periodo 1992-2005 e 2003-2009, ed il satellite TerraSAR-X dell'Agenzia Spaziale Tedesca, per il biennio 2008-2009. Oggi si dispone di una densità di dati SAR che, data la risoluzione spaziale dei satelliti tra 20 e 3 m, è maggiore di circa 2 ordini di grandezza nelle l'analisi a scala regionale e più di 3 ordini per analisi locali rispetto alle misure tradizionali su capisaldi. Ciò ha permesso la mappatura dei movimenti del suolo a scala "regionale" (100×100 km^2), locale (10×10 km^2) e puntale al livello di singole strutture. Le serie di dati SAR sono stati calibrati e validati con le misure altimetriche di livellazione, DGPS e CGPS nella rete di monitoraggio ISES- IRMA. Grazie all'elevata densità di informazioni, all'ottima risoluzione spaziale e accuratezza verticale millimetrica del monitoraggio SAR è emersa una dinamica verticali del territorio costiero Veneto diversa da quanto ottenibile utilizzando le sole tecniche di livellazione tradizionale. L'immagine attuale indica che il processo subsidenziale si esplica con una forte variabilità spaziale, sia a scala regionale che locale. L'analisi integrata dei dati altimetrici e delle numerose nuove informazioni sul sottosuolo, recentemente acquisite nell'ambito di una serie di ricerche condotte dagli Autori, ha permesso la caratterizzazione delle componenti dei movimenti verticali del suolo della pianura costiera Veneta in funzione della profondità alla quale agiscono e la loro distribuzione areale.

Key words: *Land subsidence, Deep and shallow components, Natural and anthropogenic factors, Intraplate processes, Spatial variability*

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INTRODUCTION

Land subsidence represents one of the most geologic hazards threading the low-lying coastal areas worldwide.

The Lagoon of Venice, Italy, is emblematic of a coastal area prone to progressive submersion by the rising sea. Indeed, relative sea level rise (RSLR), i.e. the interaction between eustatic rise and land subsidence, has produced 25 cm of elevation loss in Venice over the 20th century (CARBOGNIN and TOSI, 2002; CARBOGNIN *et alii*, 2004; CARBOGNIN *et alii* 2006; CARBOGNIN *et alii*, 2009) that significantly increased the flood frequency with severe damages to the urban heritage and to the lagoon morphology.

Geodetic surveys have been periodically carried out to monitor land subsidence in the Venice coastal area since the end of the 19th century. Starting from the 1980s, space-based geodetic techniques such as the Global Positioning System (GPS) have been adopted to monitor vertical movements, and mostly from the late 90's because GPS measurements reached a point where millimeter-level positioning became achievable (TOSI *et alii*, 2000; TOSI *et alii*, 2007a)

The land subsidence monitoring in the Venice coastland has been significantly improved over the last few years by space borne earth observation techniques based on Synthetic Aperture Radar (SAR) -based interferometry. SAR interferometry has been used to complement the ground-based methods. Firstly, Differential InSAR (DInSAR) and afterward Interferometric Point Target Analysis (IPTA) have been applied (TOSI *et alii*, 2002; TEATINI *et alii*, 2005; TEATINI *et alii*, 2007; STROZZI *et alii*, 2009).

This work describes the major results achieved by the ISMAR, DMMMSA, and GAMMA REMOTE SENSING Working Group in recent research activities that have allowed to produce high resolution maps of the present ground vertical movements in the Veneto coastland (Italy) both at "regional" (100×100 km^2) and "local" (few km^2) scales.

GROUND VERTICAL MOVEMENTS OF THE VENETO COASTLAND

The mapping refers to the three periods 1992-2005, 2003-2007, and 2008-2009 and is based on images acquired by the

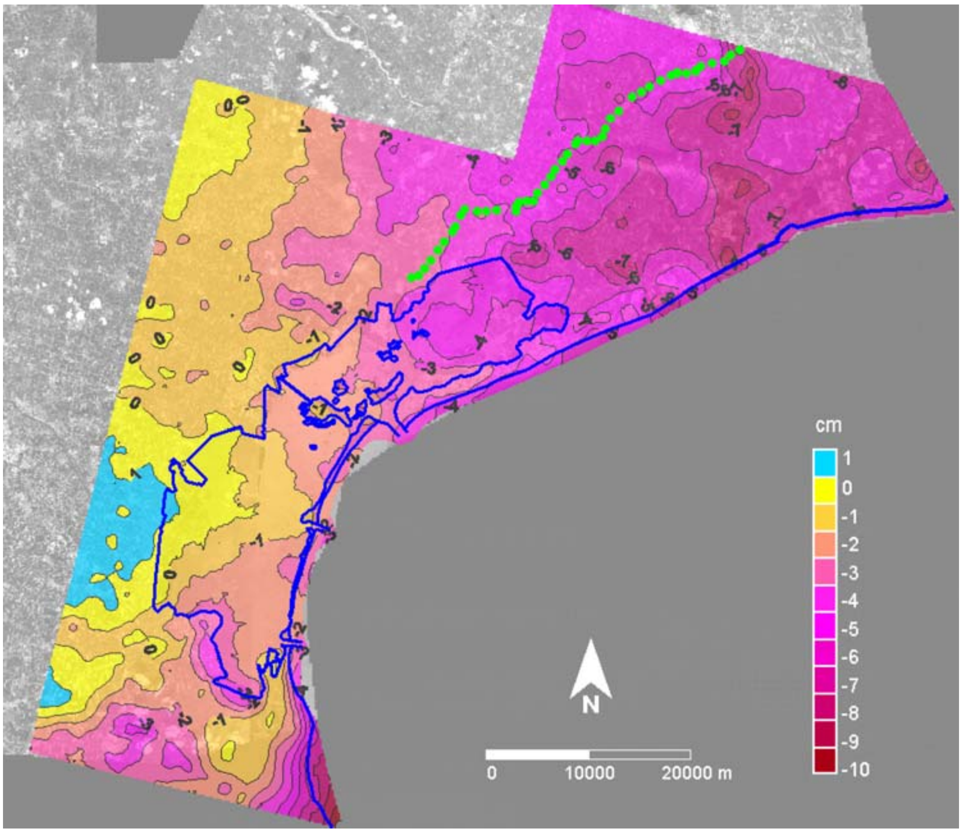

Fig. 1 – Map of the 1992-2007 ground vertical movements (cm) obtained by the integration of ERS-1/2 and ENVISAT IPTA results. Green dots: position of the IGM34 (IRMA54) leveling line benchmarks used for the comparison between IPTA and leveling results.

ERS-1/2 and ENVISAT satellites of the European Space Agency and the new TerraSAR-X launched by the German Space Agency, respectively. Figure 1 shows the total displacements occurred form 1992 to 2007 and obtained by the integration of ERS 1/2 and ENVISAT acquisitions. The calibration and validation of the SAR data using high precision spirit levelling (Figure 2) and differential and continuous Global Positing System (GPS) allowed to verify the high accuracy of the (SAR)-based interferometric analyses.

The investigation on the Veneto coastland pointed out a significant spatial variability of the ground vertical movements, both at regional and local scales, and displacement rates ranging from a slight (1-2 mm/yr) uplift to a serious subsidence of more than 10 mm/yr.

Tectonics, differential consolidation of the Pleistocene and Holocene deposits, and human activities, such as groundwater withdrawals, land reclamation of marshes and swamp areas, and farmland conversion into urban areas, superimpose to produce the observed displacements.

According to Tosi *et alii,* 2009, the displacement components have been distinguished on the basis of the depth of their occurrence.

Deep causes, acting at a depth generally greater than 400-600 m below m.s.l., refer to downward movements of the pre-Quaternary basement and land uplift (up to 2 mm/yr) most likely related to neo-tectonic activity connected with the Alpine thrust belts and a NW-SE fault system.

The displacement factors located in the medium depth interval, i.e. between 400 and 50 m below m.s.l., are of both natural and anthropogenic origin. The former refers to the Medium-Late Pleistocene deposits that exhibit a larger cumulative thickness of clayey compressible layers at the lagoon extremities with respect to the central lagoon area where stiffer sandy formations prevail. Land subsidence due to aquifer exploitation mainly occurs in the north-eastern sector of the coastland where thousands of active wells are located.

In a 10-15 km wide coastal strip the thickness, texture, and sedimentation environment of the Holocene deposits (Tosi *et alii*, 2007b; Tosi *et alii*, 2007c; Zecchin *et alii*, 2008;

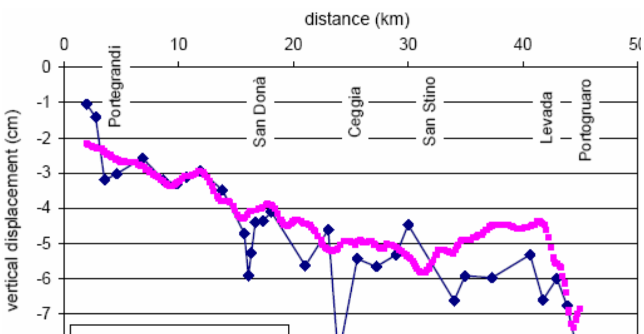

Fig. 2 – Comparison between leveling and IPTA results along the IGM34 (IRMA54) line.

RIZZETTO *et alii*, 2009; TOSI *et alii*, 2009; ZECCHIN *et alii*, 2009) play a significant role in controlling shallow causes of land subsidence. Other factors that contribute in increasing land sinking at a smaller areal extent are the salinization of clay deposits due to saltwater intrusion and biochemical oxidation of out cropping peat soils (GAMBOLATI *et alii,* 2005; CARBONGNIN *et alii,* 2006). Even the load of buildings and structures after the conversion of farmland into urbanized areas causes local shallow compaction.

REFERENCES

CARBOGNIN L. & TOSI L. (2002) - *Interaction between Climate Changes, Eustacy and Land Subsidence in the North Adriatic Region, Italy*. Marine Ecology, **23**(1), 38-50.

CARBOGNIN L., TEATINI P. & TOSI L. (2004) - *Relative land subsidence in the lagoon of Venice, Italy, at the beginning of the new millennium.* Jornal of Marine Systems **51**, 345–353, doi:10.1016/j.jmarsys.2004.05.021.

CARBOGNIN L., GAMBOLATI G., PUTTI M., RIZZETTO F., TEATINI P. & TOSI L. (2006) - *Soil contamination and land* SUBSIDENCE *raise concern in the Venicewatershed, Italy*. In: C.A. Brebbia, M.E. Conti & E. Tiezzi (Eds.) - Management of Natural Resources, Sustainable Development and Ecological Hazards. WIT transactions on Ecology and the Environment, **99**, 691-700. WIT Press, Southampton, UK, doi:10.2495/RAV060671.

CARBOGNIN L., TEATINI P., TOMASIN A. & TOSI L. (2009) - *Global change and relative sea level rise at Venice: what impact in term of flooding.* Climate Dynamics, doi: 10.1007/s00382-009-0617-5.

GAMBOLATI G., PUTTI M., TEATINI P., CAMPORESE M., FERRARIS S., GASPARETTO-STORI G., NICOLETTI V., RIZZETTO F., SILVESTRI S. & TOSI L. (2005) - *Peatland oxidation enhances subsidence in the Venice watershed*. EOS Trans. AGU **86**(23), 217–224.

RIZZETTO F., TOSI L., ZECCHIN M., BRANCOLINI G., BARADELLO L. & TANG C. (2009) - *Ancient geomorphological features in shallows of the Venice Lagoon (Italy).* Journal of Coastal Research, **56**, 752-756.

STROZZI T., TEATINI P. & TOSI L. (2009) - *TerraSAR-X reveals the impact of the mobile barrier works on the Venice coastal stability.* Remote Sensing of Environment (accepted).

TEATINI P., TOSI L., STROZZI T., CARBOGNIN L., WEGMÜLLER, U. & RIZZETTO F. (2005) - *Mapping regional land displacements in the Venice coastland by an integrated monitoring system.* Remote Sensing of Environment **98**, 403-413, doi:10.1016/j.rse.2005.08.002.

TEATINI P., STROZZI T., TOSI L., WEGMÜLLER U., WERNER C. & CARBOGNIN L. (2007) - *Assessing short- and long-time displacements in the Venice coastland by synthetic aperture radar interferometric point target analysis.* Journal of Geophysical Research **112**, F01012, doi:10.1029/2006JF000656.

TOSI L., CARBOGNIN L., TEATINI P., ROSSELLI R. & GASPARETTO STORI G. (2000) - *The ISES Project subsidence monitoring of the catchment basin south of the Venice Lagoon (Italy).* In L. Carbognin, G. Gambolati & A. Johnson (Eds.) - Land Subsidence, **II**, 113-126, La Garangola, Padova, Italy.

TOSI L., CARBOGNIN L., TEATINI P., STROZZI T. & WEGMÜLLER U. (2002) - *Evidences of the present relative land stability of Venice, Italy, from land, sea, and space observations.* Geophysical Research Letters **29**, doi:10.1029/2001GL013211.

TOSI L., TEATINI P., CARBOGNIN L. & FRANKENFIELD J. (2007a) - *A new project to monitor landsubsidence in the northern Venice coastland (Italy).* Environmental Geology **52**(5), 889–898, doi 10.1007/s00254-006-0530-8.

TOSI L., RIZZETTO F., BONARDI M., DONNICI S., SERANDREI BARBERO R. & TOFFOLETTO F. (2007b) - *Note illustrative della Carta Geologica d'Italia alla scala 1:50.000, Foglio 128 – Venezia.* APAT, Dip. Difesa del Suolo, Servizio Geologico d'Italia, SystemCart, Roma, 164 pp., 2 maps.

TOSI L., RIZZETTO F., BONARDI M., DONNICI S., SERANDREI BARBERO R. & TOFFOLETTO F. (2007c) - *Note illustrative della Carta Geologica d'Italia alla scala 1:50.000, Foglio 148-149 – Chioggia-Malamocco.* APAT, Dip. Difesa del Suolo, Servizio Geologico d'Italia, SystemCart, Roma, 164 pp., 2 maps.

TOSI L., TEATINI P., CARBOGNIN L. & BRANCOLINI G. (2009) - *Using high resolution data to reveal depth-dependent mechanisms that drive land subsidence: The Venice coast, Italy*. Tectonophysics, doi:10.1016/j.tecto.2009.02.026.

TOSI L., RIZZETTO F., ZECCHIN M., BRANCOLINI G. & BARADELLO, L. (2009) - *Morphostratigraphic framework of the Venice Lagoon (Italy) by very shallow water VHRS surveys: Evidence of radical changes triggered by human-induced river diversion.* Geophysical Research Letters, **36**, L09406, doi:10.1029/2008GL037136.

ZECCHIN M., BARADELLO L., BRANCOLINI G., DONDA F., RIZZETTO F. & TOSI, L. (2008) - *Sequence stratigraphy based on high resolution seismic profiles in the late Pleistocene and Holocene deposits of the Venice area.* Marine Geology, **253**, 185-198, doi: 10.1016/j.margeo.2008.05.010.

ZECCHIN M., BRANCOLINI G., TOSI L., RIZZETTO F., CAFFAU M. & BARADELLO L. (2009) - *Anatomy of the Holocene succession of the southern Venice Lagoon revealed by very high resolution seismic data.* Continental Shelf Research, **29**(10), 1343-1359.10.1016/j.csr.2009.03.006.