THEMATIC AND LAND SUBSIDENCE MAPS OF THE LAGOON OF VENICE FROM ERS SAR INTERFEROMETRY

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Abstract.

Within the Co.Ri.La. project 3.2 on Hydrodynamics and Morphology, interferometric radar images from the ERS-1/2 satellites from 1993 to 2000 have been used to generate a subsidence map of the Lagoon of Venice. The SAR interferometric land subsidence map pictures very well the different displacement rates of the various compartments of the Lagoon. The SAR interferometric displacement map is discussed in comparison to the levelling results available through the ISES project. A geocoded thematic map of the Lagoon of Venice at 30 m resolution is also presented.

1. *Introduction.*

The European Remote Sensing Satellites ERS-1 and ERS-2 are the first of a series of spacecrafts intended to provide a pre-operational service of ocean, ice and land observations for the benefit of a large user community. One of the main instruments of both ERS satellites is a Synthetic Aperture Radar (SAR) operating at 5.3 GHz (C-band) with one polarization for imaging the Earth's surface. Recently, the development of SAR interferometry has proved that not only the amplitude of the radar signal

but also the phase carries important information for remote sensing applications (Bamler and Hartl, 1998, Rosen et al., 2000, Strozzi et al., 2001). In particular, differential SAR interferometry can be used to measure coherent displacements at cm to mm resolution. Spectacular new results resulted for geophysical sciences with earthquake displacement, volcano deformation, glacier dynamics and land subsidence 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 analyses. In the case of the Venetian area, where high precision levelling surveys are currently available only around the Lagoon margin and along two lines from Venezia to Treviso and from Mestre to Padova, SAR interferometry has the capability to monitor the vertical displacements of all the built-up areas not fully covered with levelling results.

Within the Co.Ri.La. project on Hydrodynamics and Morphology, interferometric radar images from the ERS-1/2 satellites from 1993 to 2000 have been used to generate a single subsidence map. The SAR interferometric displacement data contributes to the control of the ground vertical movements as one of the possible components of the erosion and deposition processes. The SAR interferometric land subsidence map of the Lagoon of Venice very well pictures the different displacement rates of the various compartments of the Lagoon. The SAR interferometric displacement map is discussed in comparison to the levelling results available through the ISES (Intrusione Salina e Subsidenza) project (Tosi et al., 2000, Carbognin et al., 2001). Finally, a geocoded thematic map of the Lagoon of Venice at 30 m resolution computed with a Tandem interferometric coherence, the backscattering intensity and the backscattering intensity change is also presented.

2. *Differential SAR interferometry.*

With SAR interferometry the phase difference of two satellite radar images acquired from slightly different positions and at different times is computed (Bamler and Hartl, 1998, Rosen et al., 2000, Strozzi et al., 2001). The phase signal derived from an 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 differential SAR interferometry is to subtract the topography related phase (for instance

Table 1 - Interferometric SAR images used in the computation of the land subsidence map of the Lagoon of Venice.

Orbits	Dates	Perpendicular Baseline	Time interval
07782_00477	10.01.93_24.05.95	3 m	864 days
00477_10497	24.05.95_23.04.97	7 m	700 days
10497_20517	23.04.97_24.03.99	-21 m	700 days
11289_05487	12.09.93_08.05.96	-17 m	969 days
25160_18012	07.05.96_30.09.98	-11 m	876 days
18012_26529	30.09.98_17.05.00	-49 m	595 days

simulated from a Digital Elevation Model) from the interferogram to derive a displacement map. The main characteristics of this technique are a spatial resolution on the order of 30 m and a sub-cm vertical accuracy. The main limitation is the possibility to derive subsidence information only over built-up or sparsely vegetated areas (i.e. where stable structures permit the formation of a coherent phase signal over time).

Nine SAR images from the European Remote Sensing Satellites ERS-1 and ERS-2 from 1993 to 2000 have been used in this study (Tab. 1). In order to generate a single subsidence map with reduced errors, 6 differential interferograms have been combined. Land subsidence was computed by assuming displacement in the vertical direction only. The map was geocoded to the Italian cartographic system Gauss-Boaga, zone 2, datum Roma 1940 with a pixel spacing of 30 m.

In addition to the interferometric phase itself, the interferometric coherence, which is a measure for the variance of the interferometric phase, is a very useful source of information on scene properties often complementary to the backscattered intensity. A geocoded thematic map of the Lagoon of Venice at 30 m resolution was computed by combination of a Tandem interferometric coherence, the backscattering intensity and the backscattering intensity change and is presented in Fig. 1.

3. *Land subsidence map of the Lagoon of Venice and comparison with ISES levelling surveys.*

The SAR-derived subsidence map of the Lagoon of Venice for the time period 1993-2000 at a spatial resolution of 30 m is shown in Fig. 2. The pixel corresponding to the benchmark Nodale 63 (ex 24') in Treviso

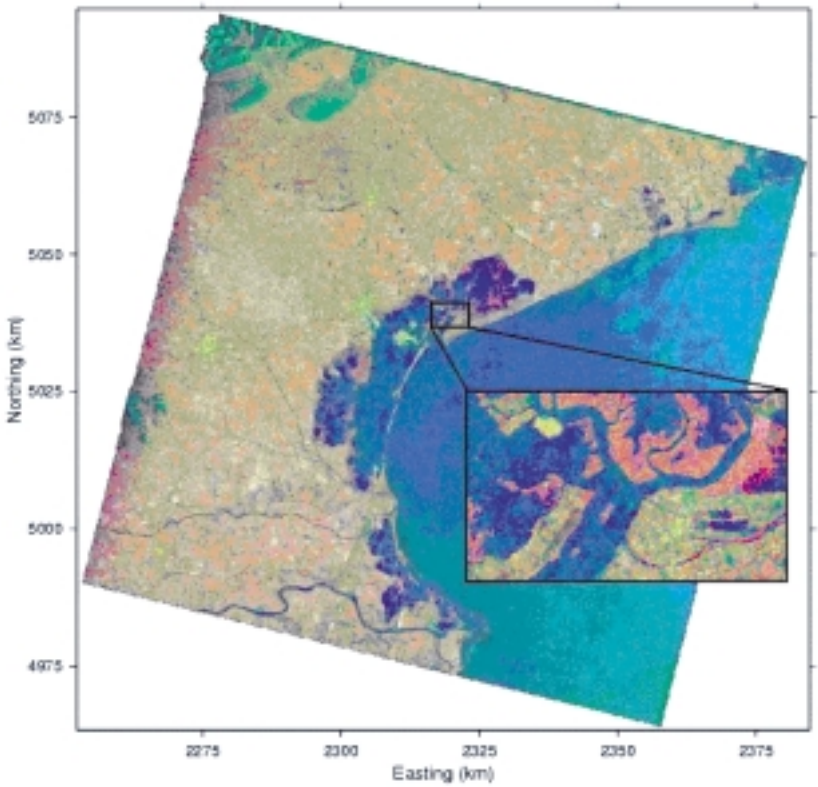

Fig. 1 - RGB color composite of interferometric coherence of the ERS-1/2 Tandem pair of the 7 and 8 May 1996, the averaged backscattering intensity for the time period 1993-2000 and the backscattering intensity change for the time period 1993-2000. The thematic map has a resolution of 30 m (see inset).

(that has been already considered stable in the ISES project) was considered the stable reference. The vertical displacement rates of the built-up areas are represented in a color scale between +1.0 and -5.0 mm/year. The incoherent areas (i.e. where it was not possible to measure subsidence) are shown without colors. The land subsidence rates from SAR interferometry are compared to those determined with levelling surveys in the frame of the ISES project along the lines Mestre - Venezia, Brondolo - Mestre - Jesolo, and Brondolo - Litorale di Lido - Jesolo (see Figs. 3 to 5).

For the 87 points where information is available from both surveying techniques (levelling benchmarks and corresponding SAR pixels) the standard deviation of the difference of the vertical displacement rates bet-

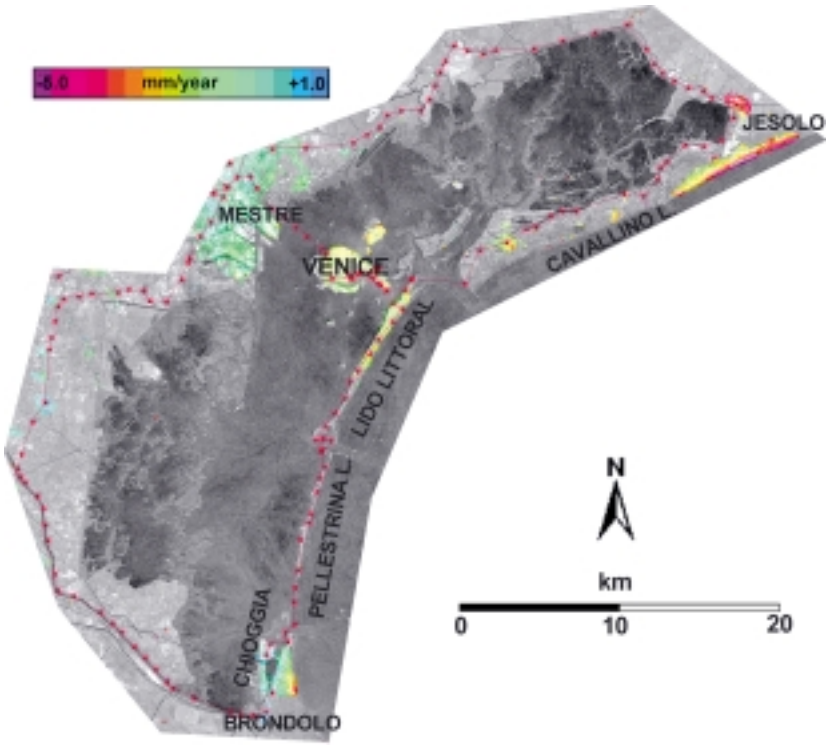

Fig. 2 - Land subsidence map (in mm/year) of the Lagoon of Venice for the time period 1993-2000 with superimposed the levelling lines used for comparison.

ween levelling surveys and SAR interferometry is 0.9 mm/year. From this number and previous works (Strozzi et al., 2001) we conclude that the accuracy of the SAR interferometric subsidence rates is on the order of ±1 mm/year, which is also the expected accuracy of the levelling surveys (Carbognin et al., 2001).

In the following, we will analyze the vertical displacement rates in the areas of Mestre-Venezia, Jesolo and the north of the Lagoon, Chioggia and the south of the Lagoon. In particular, we will give emphasis to the comparison between the 2-dimensional coverage from SAR interferometry and the linear results from levelling surveys.

The area of Mestre, Venezia and Lido Littoral (Fig. 2) is overall stable with altimetric variations included in 2 mm/year. From Figs. 3 and 4 there is a very good correspondence between the results from SAR inter-

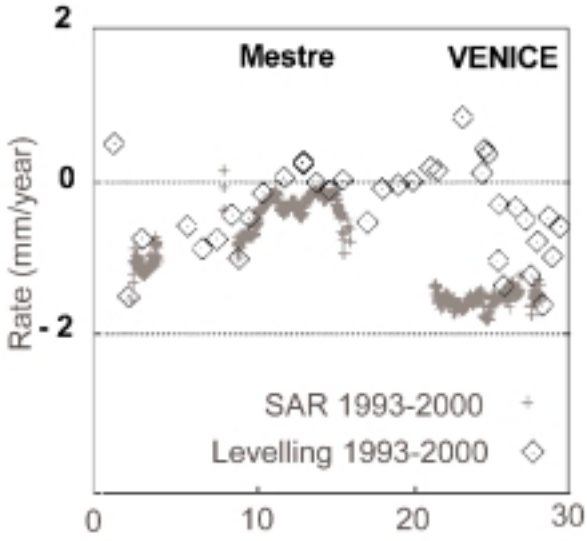

Fig. 3 - Subsidence rates (in mm/year) for the time period 1993-2000 from SAR interferometry (red crosses) and levelling surveys (black diamonds) along the levelling line Treviso - Mestre - Venezia.

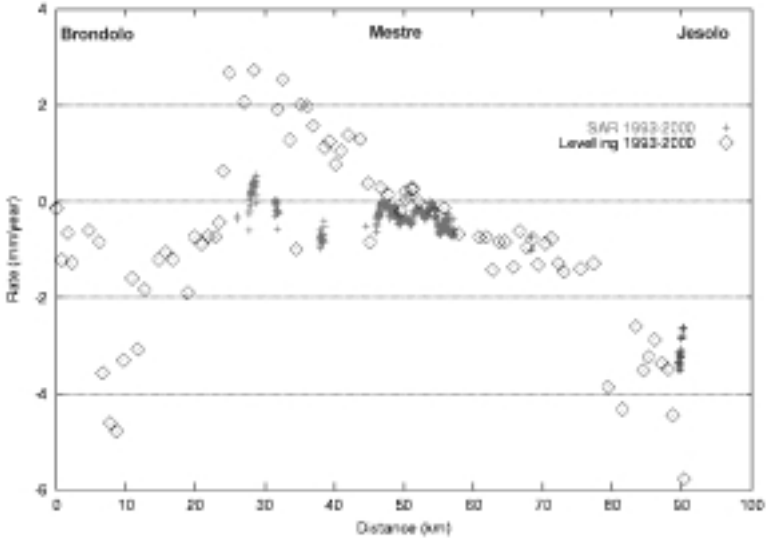

Fig. 4 - Subsidence rates (in mm/year) for the time period 1993-2000 from SAR interferometry (red crosses) and levelling surveys (black diamonds) along the levelling line Brondolo - Mestre - Jesolo.

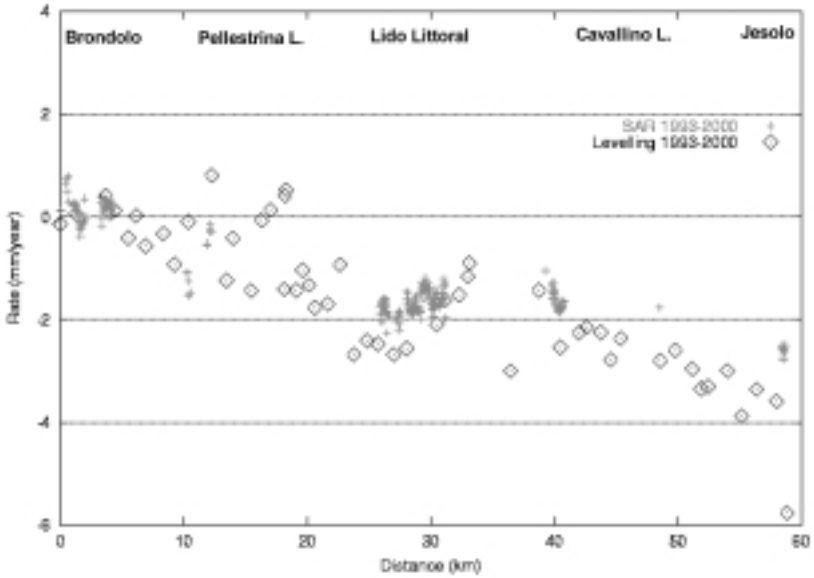

Fig. 5 - Subsidence rates (in mm/year) for the time period 1993-2000 from SAR interferometry (red crosses) and levelling surveys (black diamonds) along the levelling line Brondolo - Litorale di Lido - Jesolo.

ferometry and levelling surveys around Mestre. Along the western part of the profile in Venezia there is a certain difference between the values obtained from SAR interferometry and levelling surveys (with nevertheless a difference of less than 2 mm/year). On the other hand, for the eastern part of the profile in Venezia and for Lido Littoral (Fig. 5) the agreement between the two techniques is again very good. It is very interesting to observe an uplift of the ground in the southwest of Mestre, which is particularly evident from the levelling surveys (see Fig. 4).

For the northern part of the Lagoon, along the coast of Cavallino and Jesolo littoral (Fig. 6), we observe important subsidence rates that confirm the results of levelling surveys (see Figs. 4 and 5). In Jesolo Littoral there is a clear gradient of the subsidence rate from the coastline to the more stable areas inland. The pixels with valuable information from SAR interferometry inside of the Lagoon between Murano, Burano and S. Erasmo indicate a land subsidence rate of 1-2 mm/year with local values up to 3 mm/year (Fig. 7).

Also in the Chioggia area (Fig. 8) there is a strong gradient of the subsidence rate from the Sottomarina littoral to the stable area of the city of

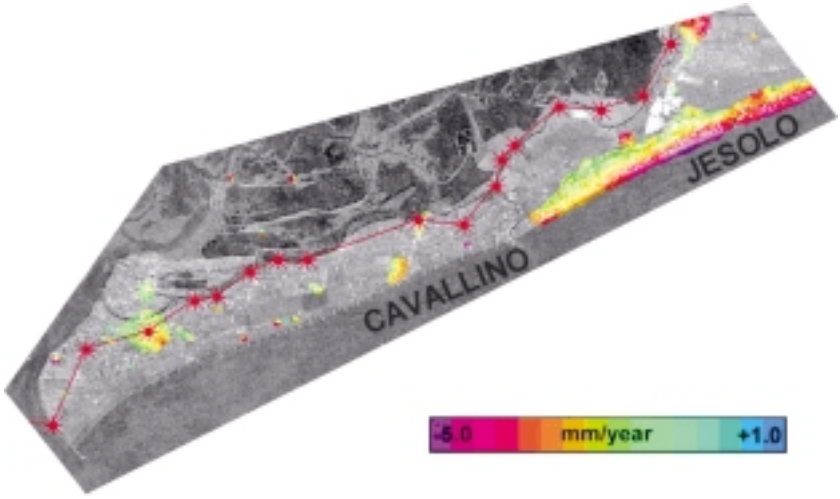

Fig. 6 - Land subsidence map (in mm/year) for the area of Cavallino - Jesolo during the time period 1993-2000 with superimposed the levelling lines used for comparison.

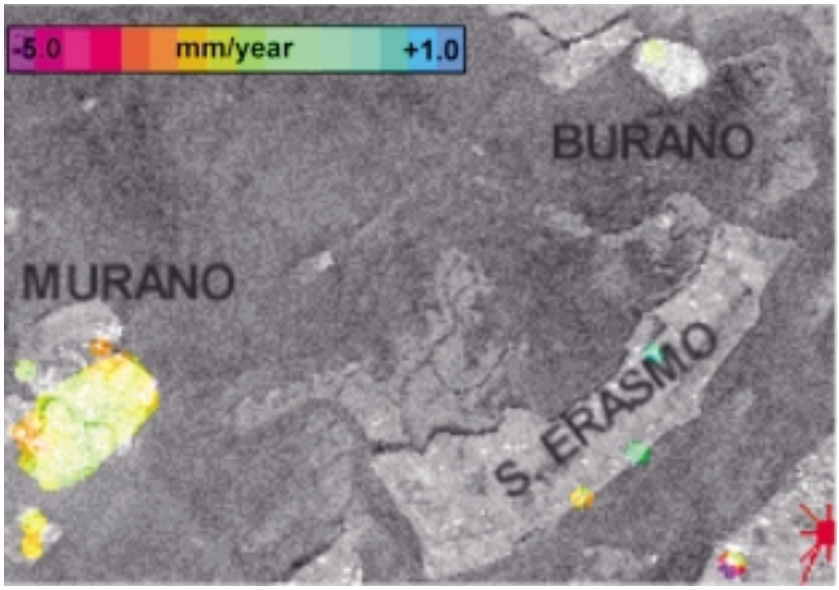

Fig. 7 - Land subsidence map (in mm/year) for the islands of Murano, Burano and S. Erasmo during the time period 1993-2000.

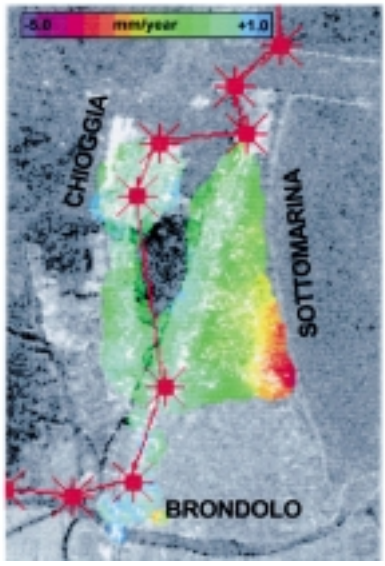

Fig. 8 - Land subsidence map (in mm/year) for the area of Chioggia during the time period 1993-2000 with superimposed the levelling lines used for comparison.

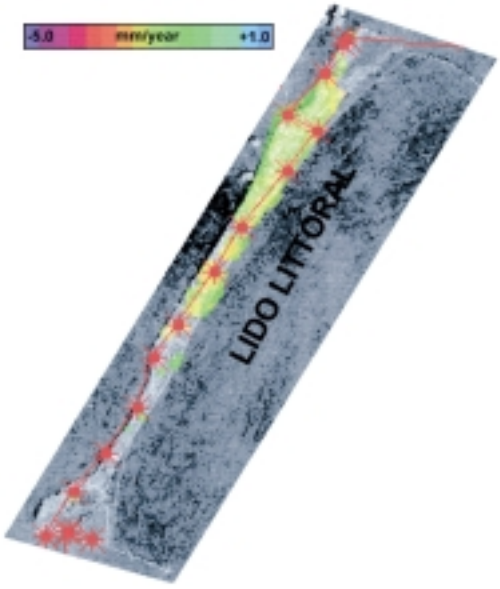

Fig. 9 - Land subsidence map (in mm/year) for Lido littoral during the time period 1993-2000 with superimposed the levelling lines used for comparison.

Chioggia. The very few pixels with valuable information from SAR interferometry for the area to the west of Chioggia indicate important subsidence values (larger than 3-4 mm/year), as observed with the levelling surveys. Between Brondolo and Lido Littoral the subsidence rates measured with SAR interferometry are very similar to those determined with levelling surveys (Fig. 5). Finally, along the Lido littoral (Fig. 9) a subsidence rate of about 2 mm/year is almost uniformly distributed over its central part.

4. *Conclusions.*

The SAR interferometric land subsidence map of the Lagoon of Venice gives confirmation to the first results available through the ISES project (Carbognin et al., 2001). Significant land subsidence rates were observed for the areas of Cavallino and Jesolo in the north of the Lagoon and for the area of Valli in the southern part. The SAR interferometric land subsidence map of the Lagoon of Venice, with an accuracy on the order of ±1 mm/year, also shows important gradients of the subsidence rate along the coastlines of Lido di Jesolo and Chioggia. Finally, we noticed a difference between the results of SAR interferometry and levelling surveys for the area in the southwest of Mestre, where the rebound determined with levelling surveys is not be completely confirmed with SAR data.

Land subsidence values could be measured with SAR interferometry only for urban and other not too small built-up areas, and therefore only for a few zones inside of the Lagoon. We expect more information for very small built-up areas by applying a different SAR interferometric technique specifically developed for point targets (Ferretti et al., 2001). The implementation of this technique for the Lagoon of Venice is part of a project that GAMMA is currently performing with ISDGM within the framework of a Data User Programme (DUP) of the European Space Agency (ESA). First results of this method should be available in about one year.

Acknowledgments.

This activity was performed in the frameworks of an ESA Data User Program and of the Co.Ri.La. project 3.2 "Hydrodynamics and Morphology of the Venice Lagoon".

We acknowledge the Venice Water Authority, Consorzio Venezia Nuova, Servizio Informativo for support. Levelling surveys courtesy ISES project (founded through the Consorzi di Bonifica Adige-Bacchiglione, Bacchiglione-Brenta and Delta Po-Adige; the Venice Water Authority; the Provincia di Padova and Provincia di Venezia; the Comune di Chioggia and the ISDGM-CNR).

ERS SAR data copyright ESA, processing GAMMA. The Italian National Geologic Survey is acknowledged for the DEM.

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