Workshop for
Land Subsidence Prevention
May 14th, 2019

LAND SUBSIDENCE IN ITALY: FROM A FEW WELL-KNOWN CASE STUDIES IN THE PAST TO SEVERAL ALMOST UNKNOWN OCCURRENCES AT PRESENT

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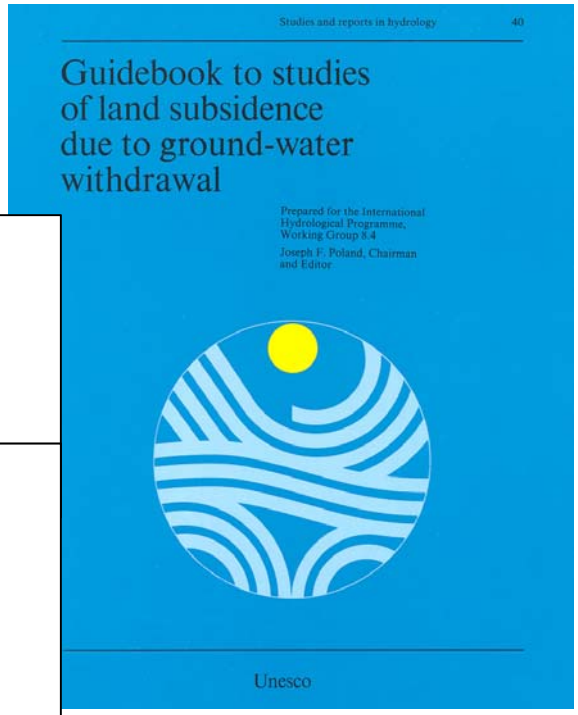
Well-known cases in the past

Three cases of land subsidence in Italy came out in the 1960s:

- Venice
- Ravenna area
- Po River delta

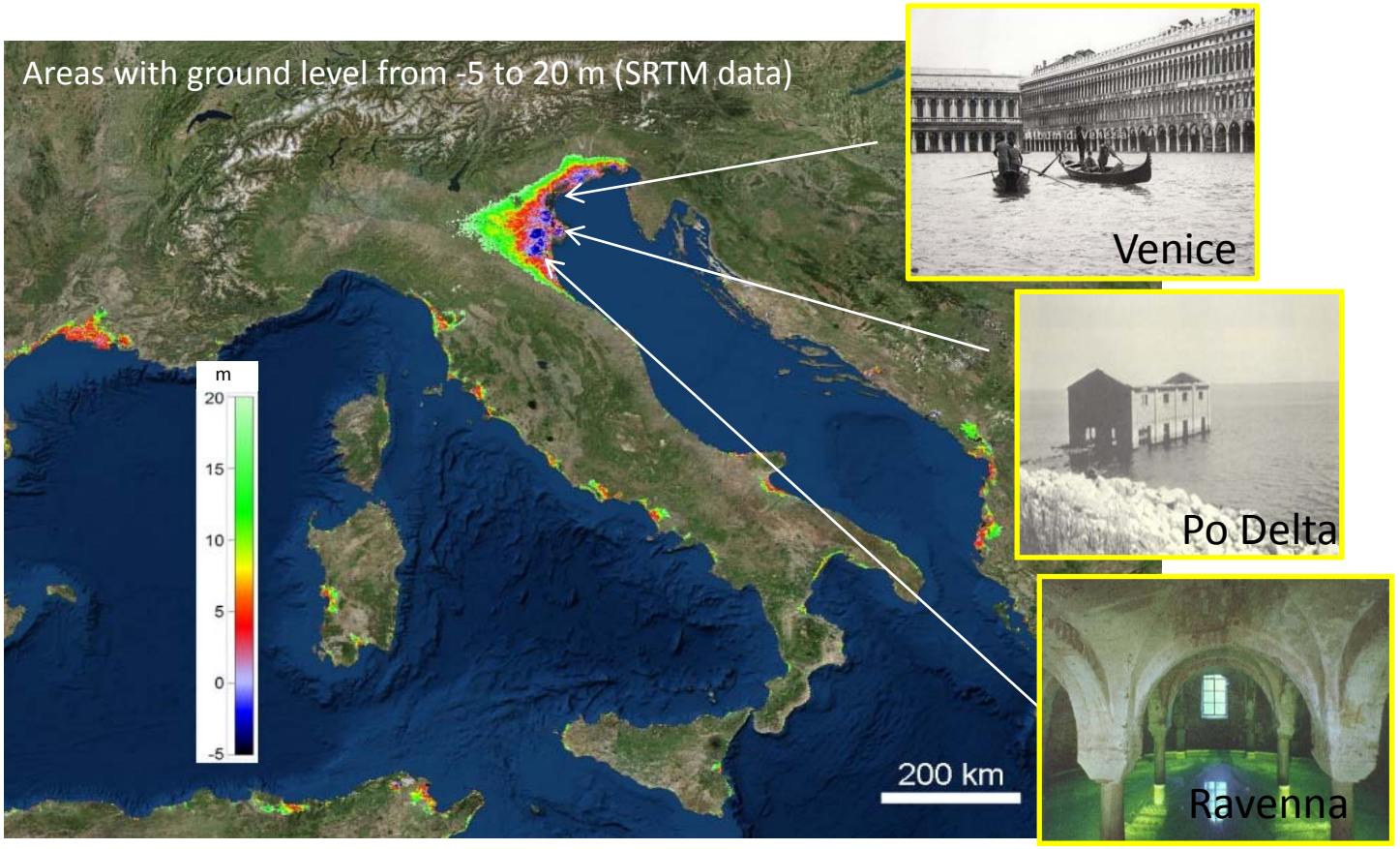
Guidebook to studies of land subsidence due to ground-water withdrawal



Guidebook to studies of land subsidence due to ground-water withdrawal *Edited by* Joseph F. Poland, 1984

Venice and Ravenna, for the concern about the survival of their Historical and Cultural heritage, unique in the world, were studied in depth and included as major examples in the J.F. Poland's Guidebook

Well-known cases in the past



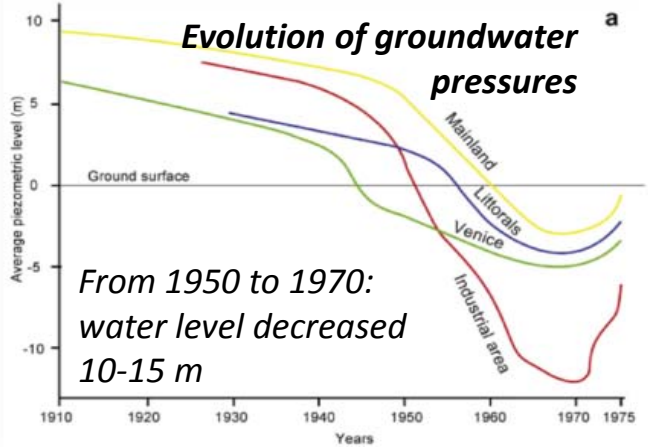
Venice, Ravenna and the Po river delta are located in the northwestern Adriatic coastland, which is the most extent lowland in Italy.

With ground elevation up to 5 m below the sea level or only 2-3 m above it, the northwestern Adriatic coast is prone to progressive submersion by the sea level rise.

Venice land subsidence: past and new knowledge

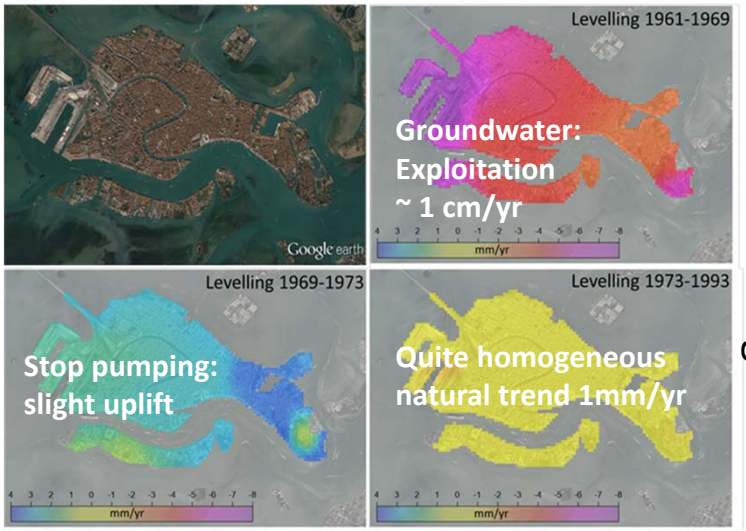
Venice is located in a foreland basin, naturally subsiding with geological rates of 0.5-1 mm/yr.

Severe induced land subsidence occurred in the 1960s due to groundwater exploitation.

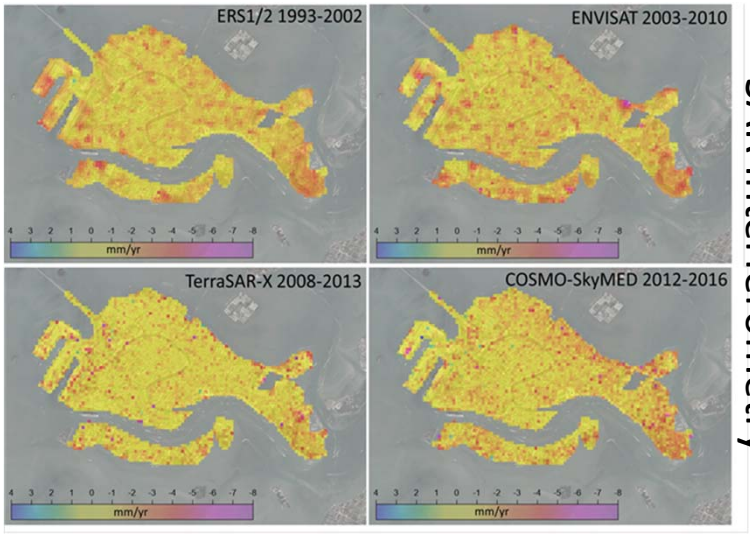


- The maximum subsidence rate of about 1 cm/yr occurred in 1969, in concomitance of 15 m lowering of groundwater level.
- Closure of the wells in early 1970s
- Natural subsidence values measured in 1993
- **Homogeneous sinking rates** obtained by leveling
- SAR-based Interferometry confirmed the reduction of subsidence rates and made possible to observed **unexpected high heterogeneity of the displacements**.

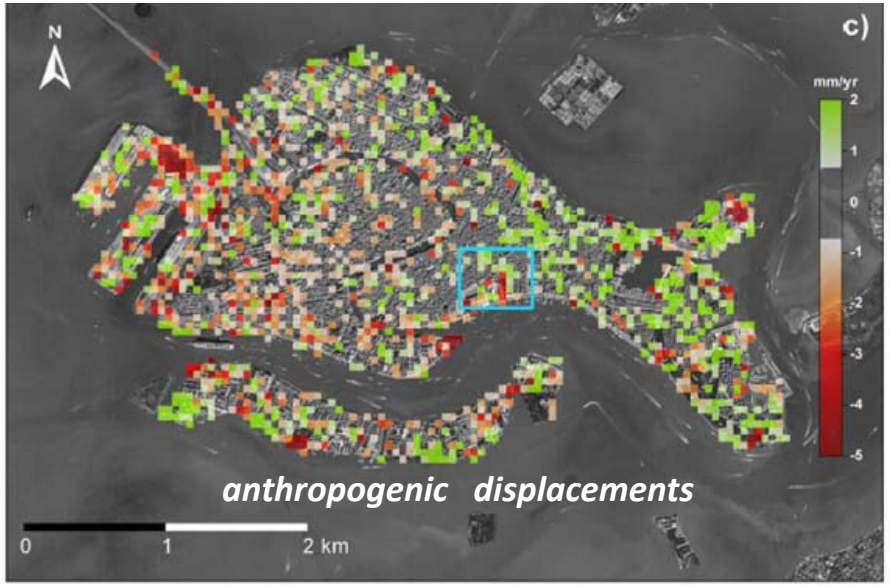
Past subsidence: 1961-1993



Recent/Present subsidence: 1993-2015



Venice land subsidence: new knowledge

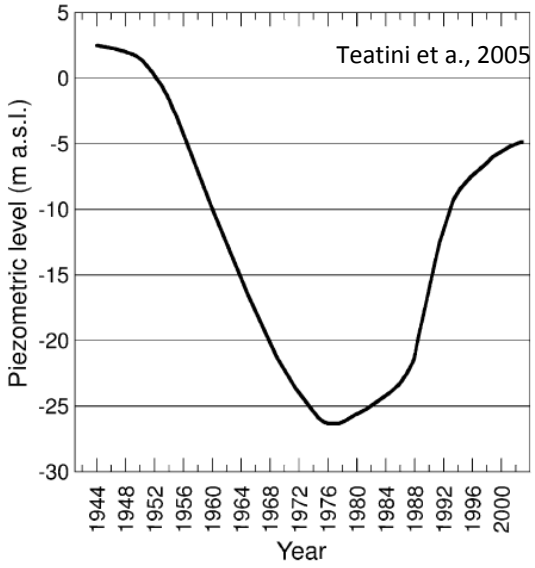


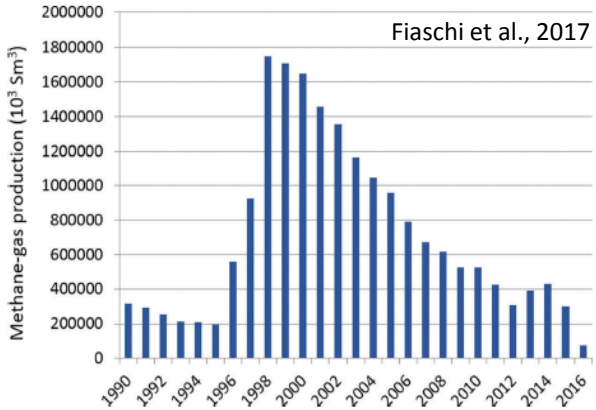
Since the **groundwater exploitation is forbidden** in the Municipality of Venice, the unexpected heterogeneity of the ground displacements has been investigated under **the hypothesis that the interventions** carried out during the last two decades for safeguarding the city **are responsible of such ground movement behavior**.

The quantification of the anthropogenic displacements has been obtained by a proper integration of interferometric datasets from C-band and X-band sensors.

Restoration works for the conservation of the historical palaces and the embankment walls (e.g., new loads, subsoil consolidations, jet grouting, well-points), dredging the canals, waves induced by the boat and ship traffic on the embankment walls, etc., produced short-term ground displacements.

Ravenna area: groundwater and gas exploitation

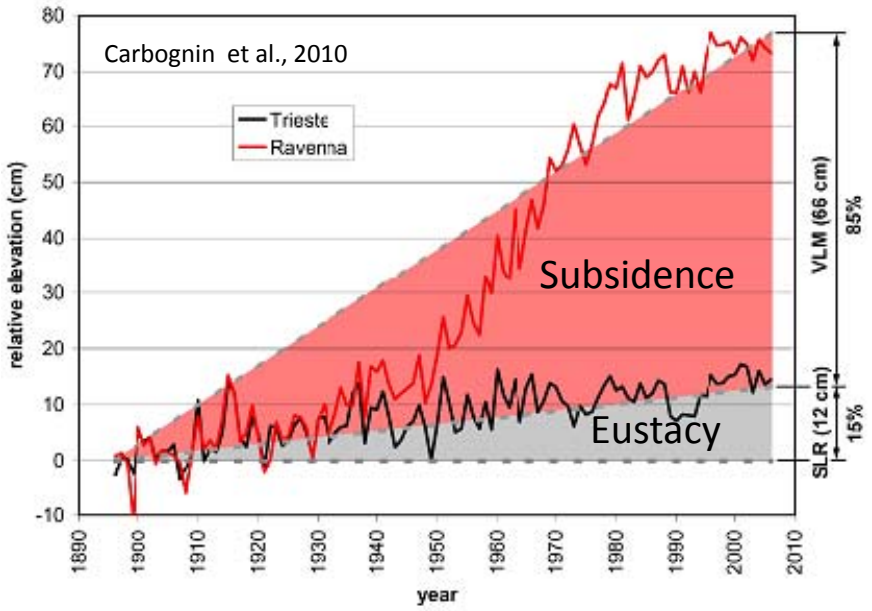




Production rate of the Angela-Angelina gas field

The Ravenna area has experienced a dramatic land settlement mainly due to the **large groundwater withdrawal** related to the local economic and tourist development started in the early 1950s.

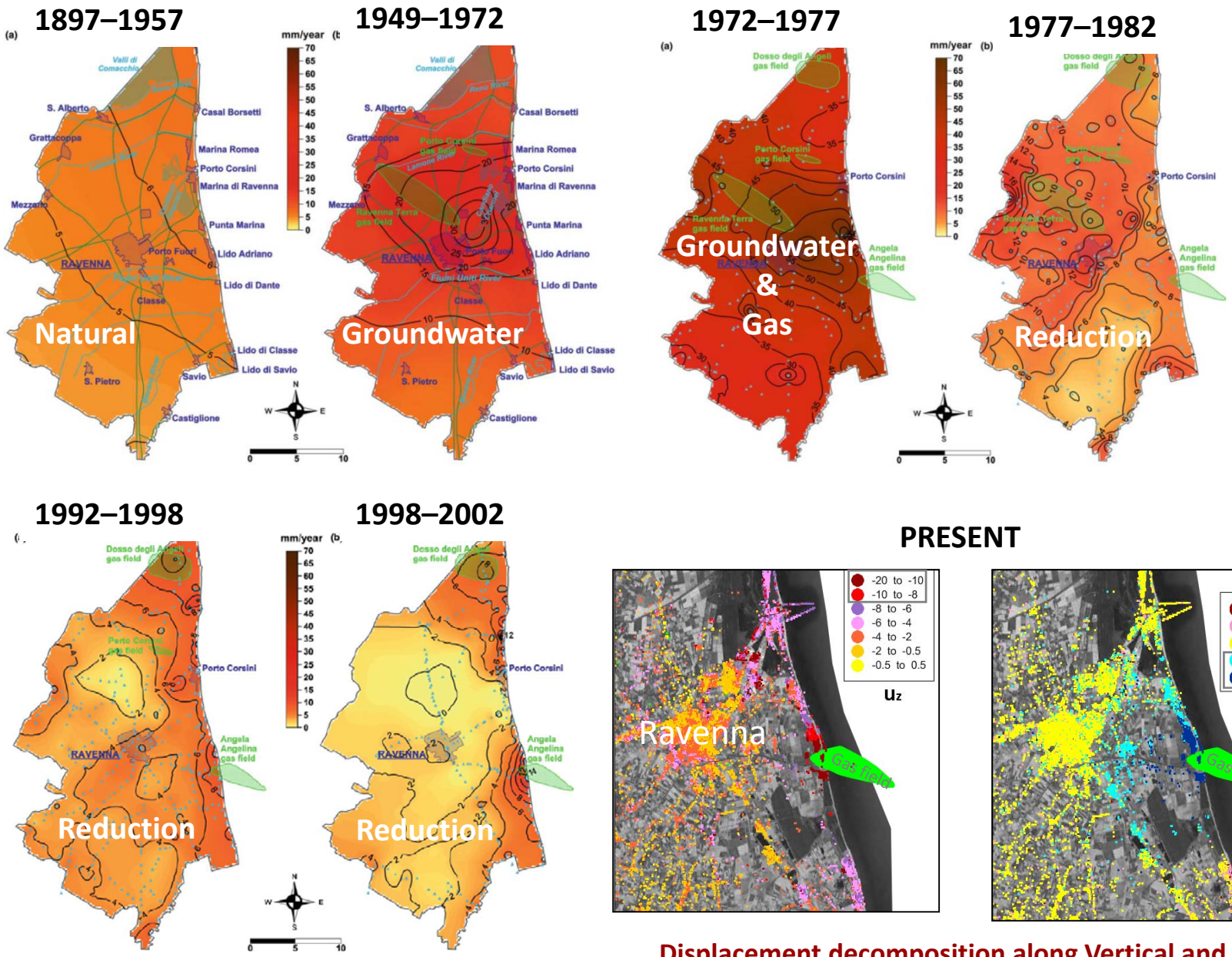
Exploitation of natural gas reservoirs contributed to land subsidence, although not nearly as much as related to groundwater extraction.



Relative Sea Level Rise at Ravenna

RSLR: 78cm; Eustacy: 12cm; Subsidence: 66cm

Ravenna area: from the past to present

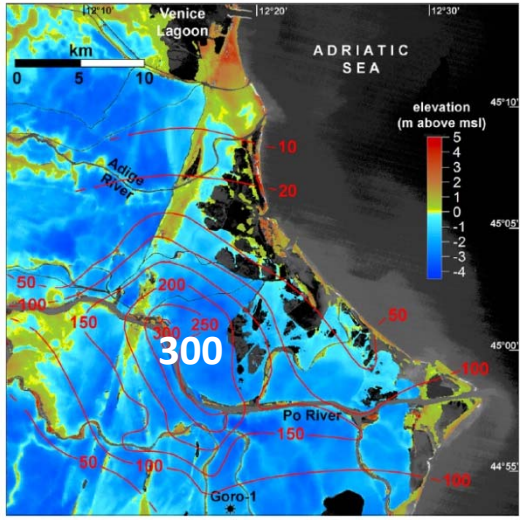


PRESENT

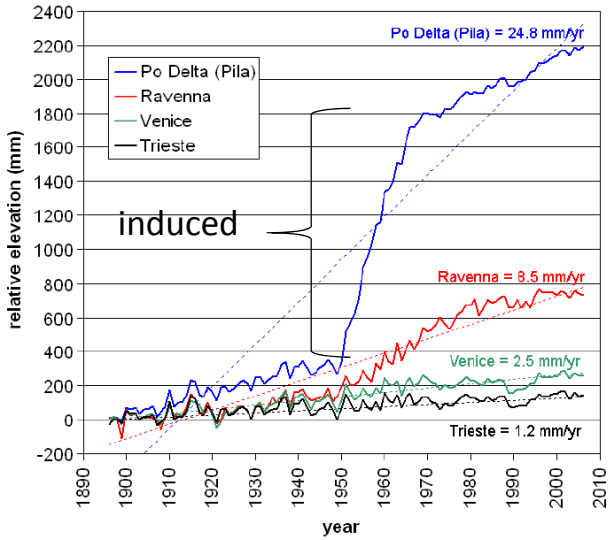
Displacement decomposition along Vertical and WE

Teatini et al., 2005

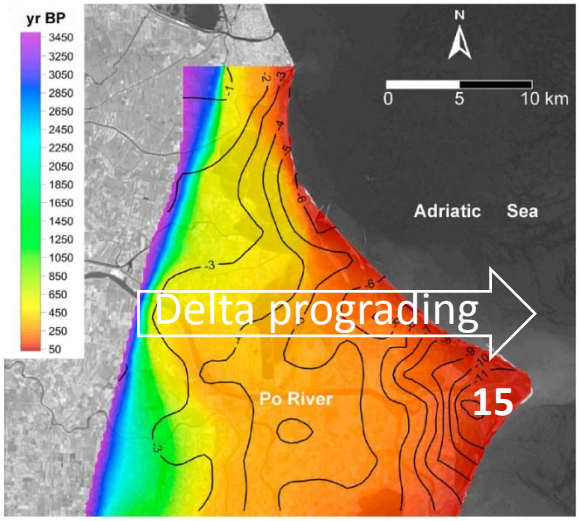
Po River delta: from 300 mm/yr in the 1950s to the present 15 mm/yr



Subsidence 1950 – 1957 (contour lines, mm/yr) superposed to the DEM



Relative Sea Level Rise at the delta tip



Subsidence (contour lines, mm/yr) superposed to formation age of the modern delta (color map, year B.P.)

Past

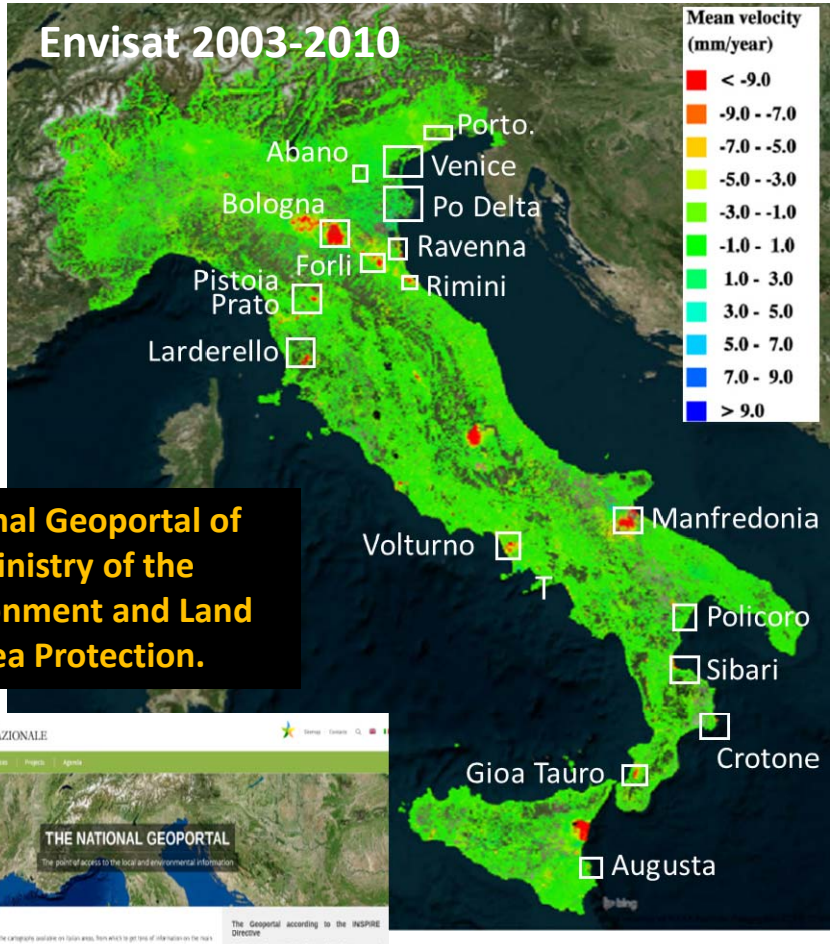
- Groundwater and gas exploitation. from 1950 to 1970.
- More than 2.5 m of subsidence.

Present

- Natural sinking rates.
- Subsidence rates are significantly correlated with the age of highly compressible Holocene deposits.

Several occurrences, almost unknown in the past, have emerged in the 2000s

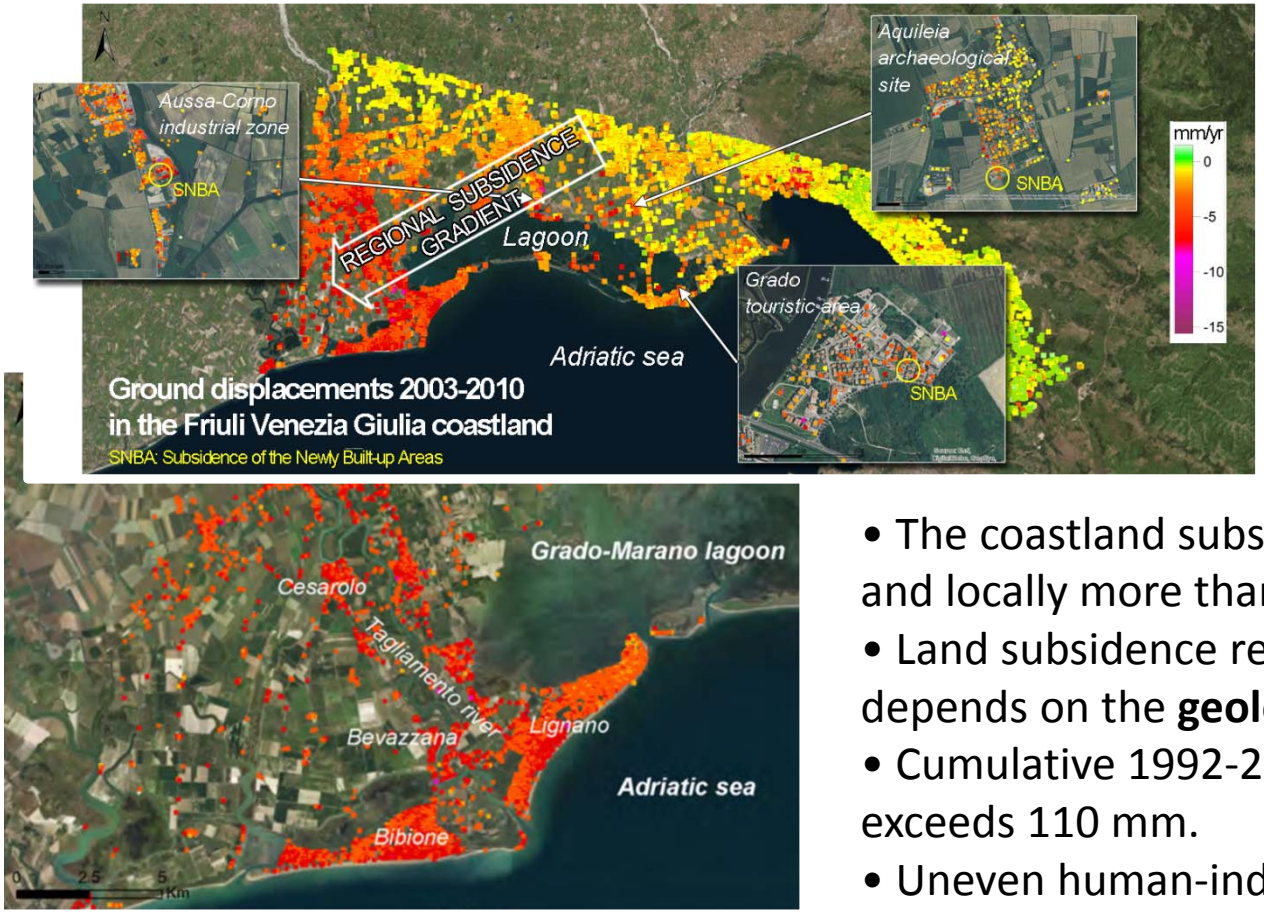
National leveling network



National Geoportal of the Ministry of the Environment and Land and Sea Protection.

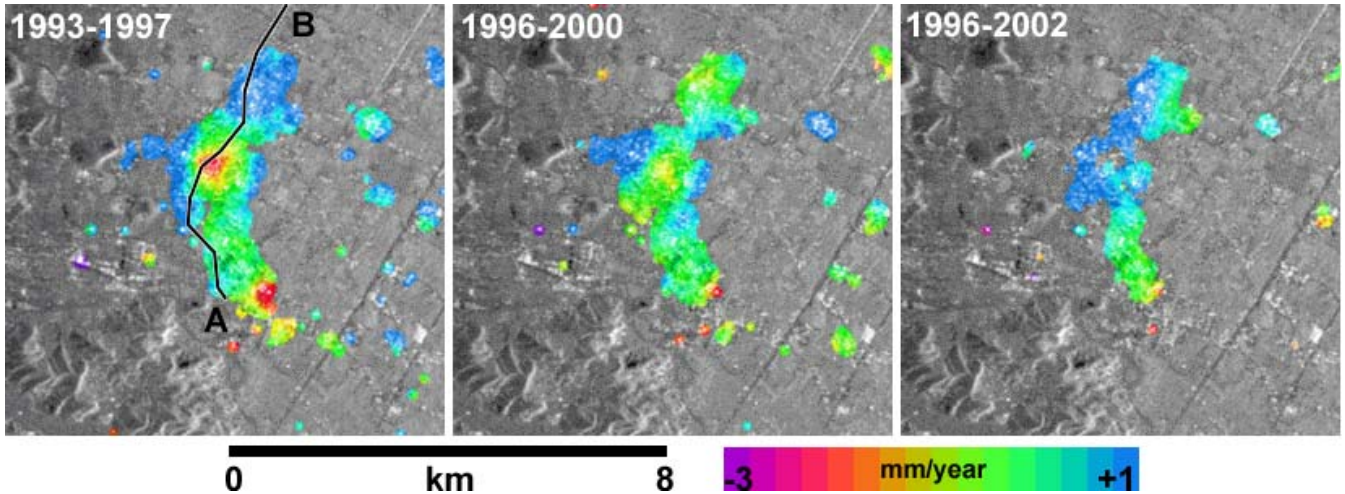
From the 2000s, the development of the SAR-based interferometry has allowed to observe several occurrences of land subsidence, previously not known or poorly investigated because of the low spatial resolution of the national leveling network.

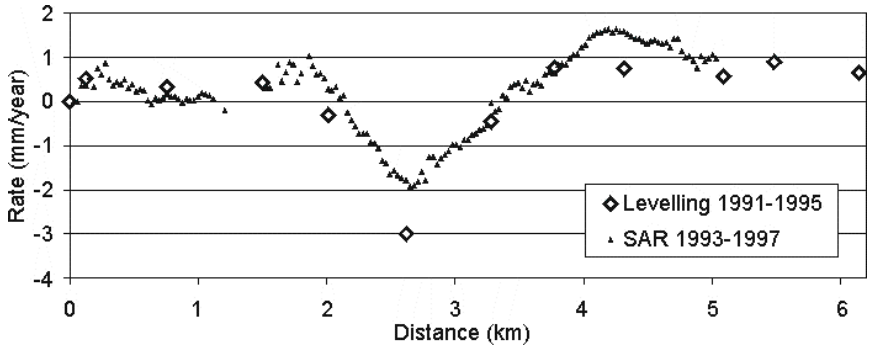
North Italy – Friuli region: Tagliamento River delta and Grado-Marano lagoons



- The coastland subsides from 1 to 5 mm/yr and locally more than 10 mm/yr.
- Land subsidence regional trend mainly depends on the **geologic characteristics**.
- Cumulative 1992-2010 land subsidence exceeds 110 mm.
- Uneven human-induced coastal subsidence is revealed at local scale.
- **Newly built-up areas** subside more than older urbanization.

North Italy: Abano and Montegrotto Terme (Euganean thermal basin - Veneto Region)

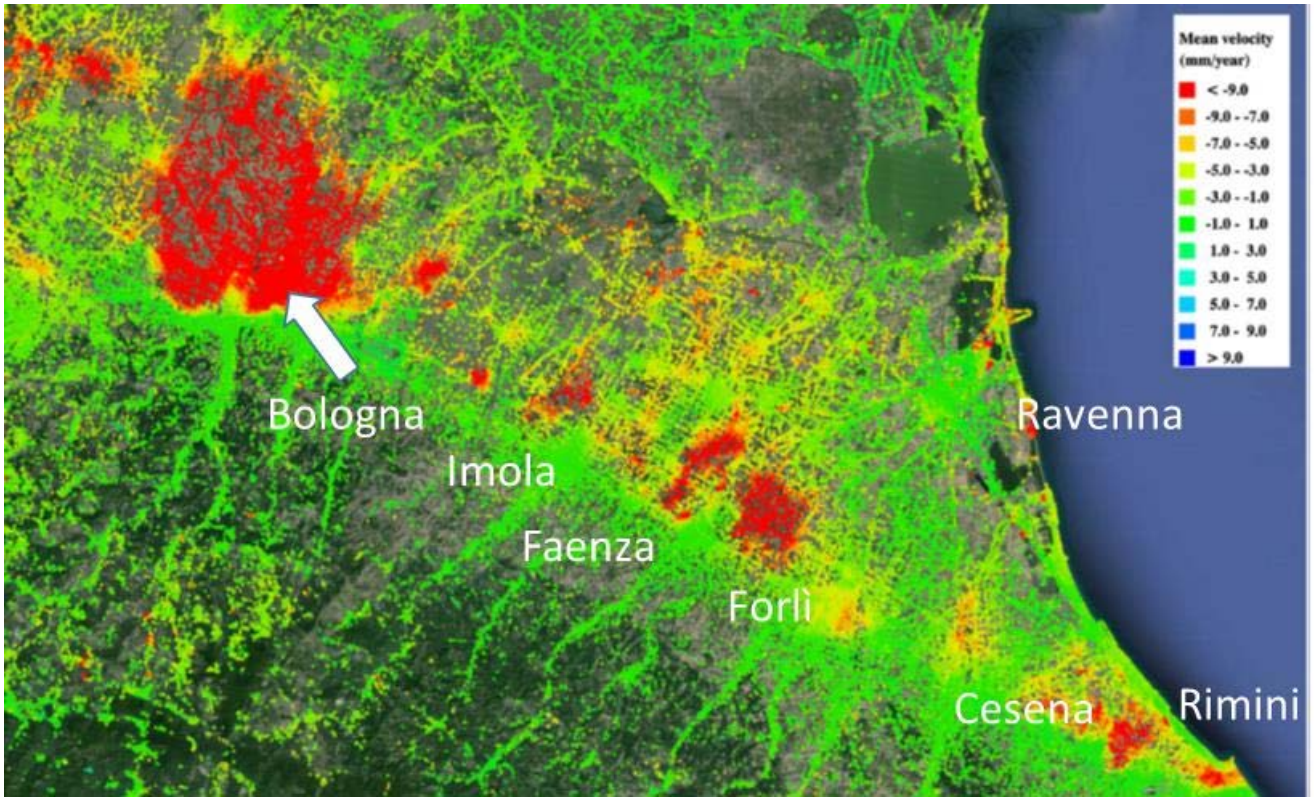




The Euganean thermal basin: **excessive withdrawal of thermal waters** caused land subsidence up to **2 cm/year in the 1980s**.

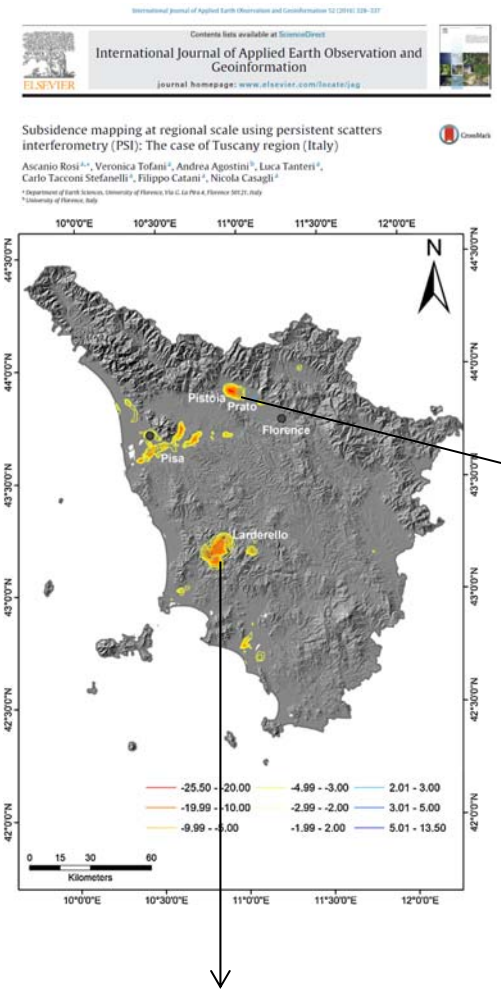
A progressive **reduction in thermal water pumping** has led to a significant reduction in the rate of sinking, which is currently only a **few millimeters per year**.

North Italy - Emilia Romagna Region: Bologna, Rimini, Cesena, Forlì, Imola, Faenza

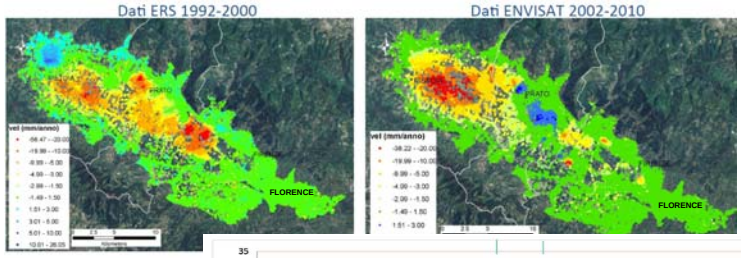


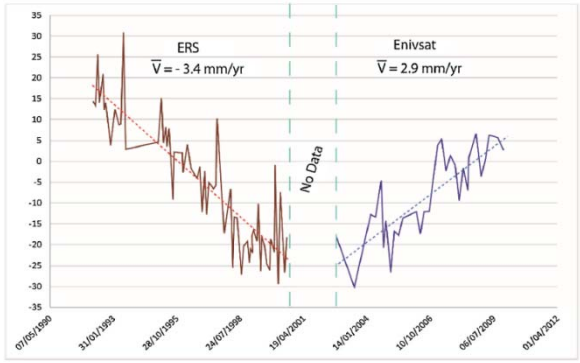
Studies conducted by the Emilia Romagna Region points out that **groundwater withdrawals** is still one of major responsible for subsidence.
Major sinking rates occur in the cities of Bologna, Rimini, Cesena, Forlì, Imola, Faenza.

Central Italy - Toscana Region: Prato, Larderello geothermal district



The principal causes of subsidence is the **overexploitation of groundwater** and the presence of high **compressive subsoil layers'**.





Prato: The change in ground motion direction can be linked to the recession that involved the textile industry of Prato city in the early 2000s, leading to a lower exploitation of groundwater.

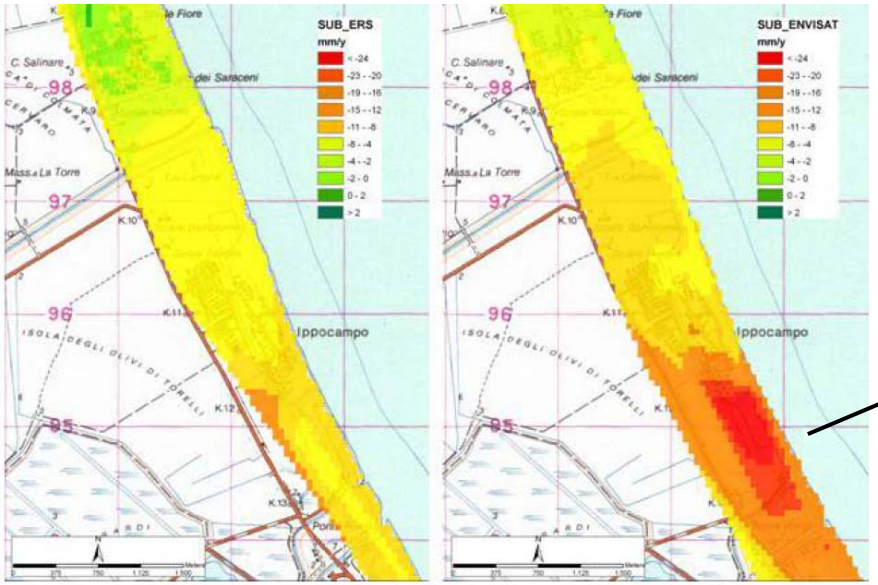
Larderello geothermal district:
the average subsidence decreased form 20–25 mm/year (1973–1983) to 10 mm/yr (2002-2010)

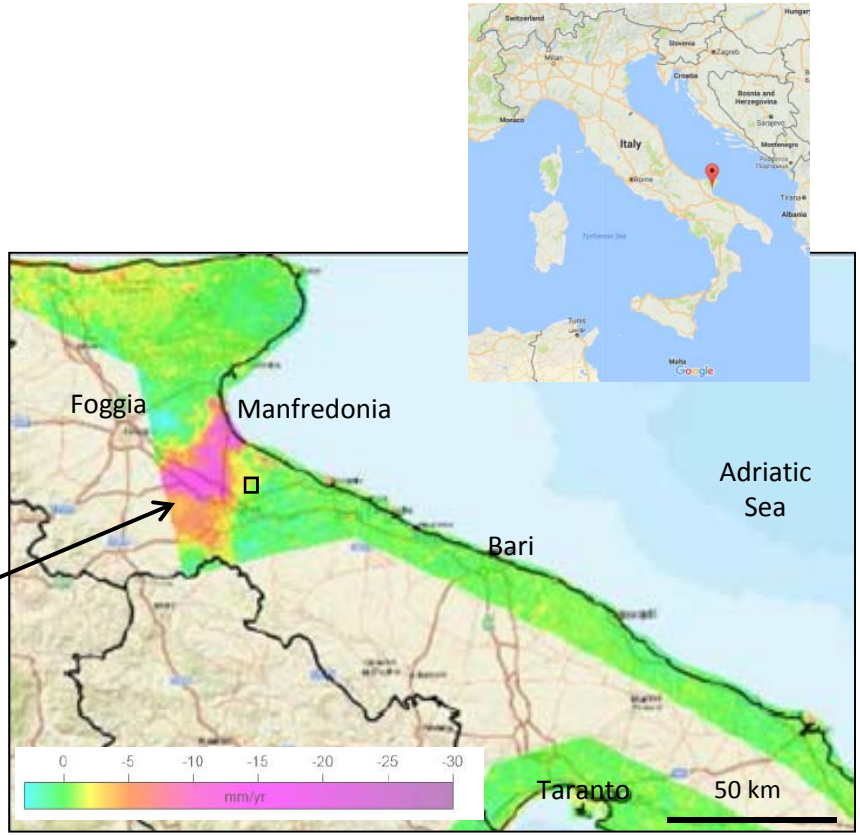
Southern Italy - Puglia Region: Manfredonia coastal plain

INVESTIGATION OF SUBSIDENCE IN THE MANFREDONIA GULF (SOUTHERN ITALY) THROUGH MULTITEMPORAL DINSAR TECHNIQUES

M. Triggiani[1], A. Refice[2], D. Capolongo[1], F. Bovenga[2], M. Caldara[1]

Proc. 'Fringe 2009 Workshop', Frascati, Italy, 30 November – 4 December 2009 (ESA SP-677, March 2010)





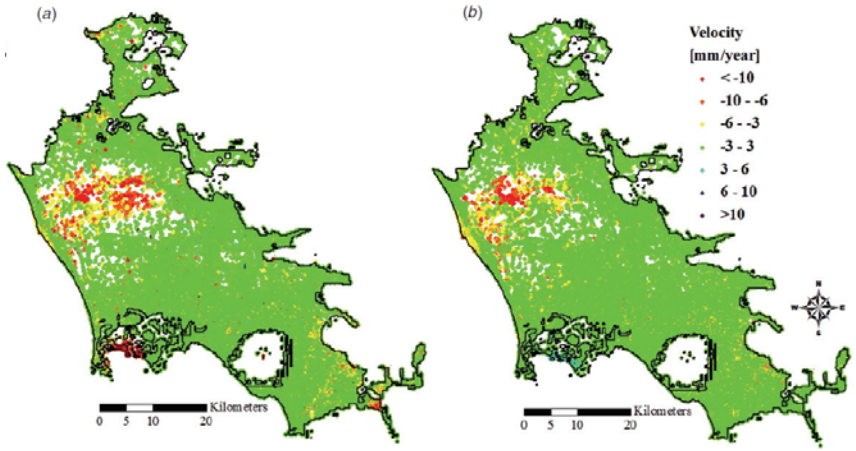
The Manfredonia plain is a low-lying reclaimed area affected by high subsidence rates. Although to date only preliminary investigations are available, significant subsidence due to **groundwater pumping for irrigation purposes superposes to the natural subsidence** because of the consolidation of recent deposits.

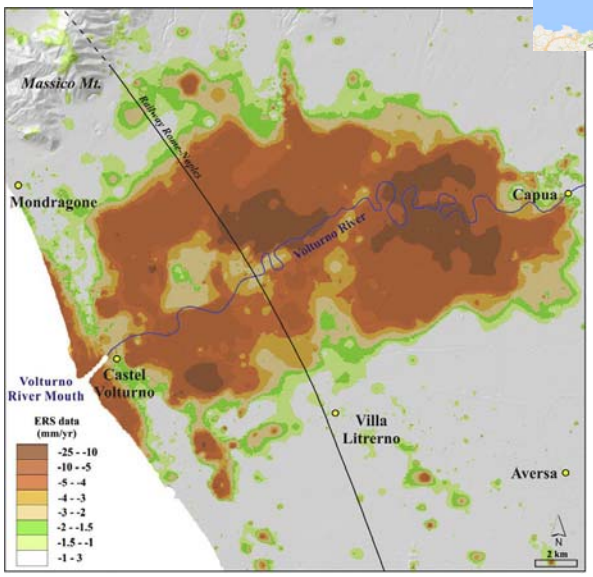
Southern Italy - Campania Region: Volturno coastal plain


Contents lists available at ScienceDirect
Estuarine, Coastal and Shelf Science
journal homepage: www.elsevier.com/locate/ecss

Coastal inundation risk assessment due to subsidence and sea level rise in a Mediterranean alluvial plain (Volturno coastal plain – southern Italy)

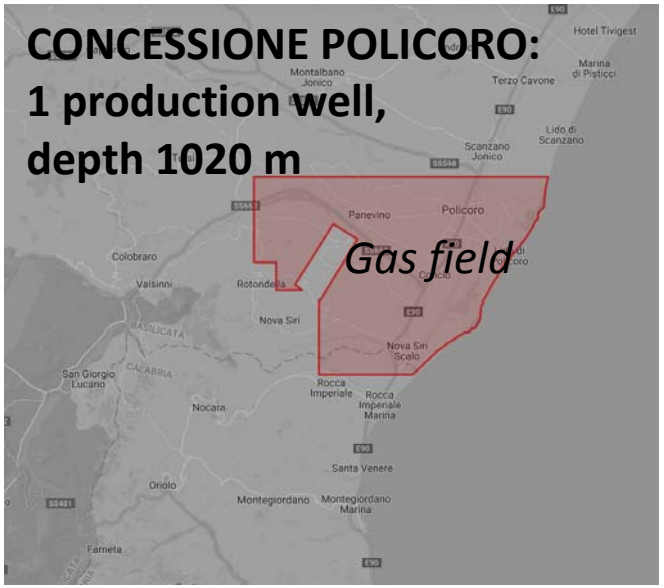
Pietro Patrizio Ciro Aucelli [a], Gianluigi Di Paola [b], Pietro Incontri [a], Angela Rizzo [a,*], Giuseppe Vilardo [c], Guido Benassai [d], Berardino Buonocore [a], Gerardo Pappone [a]



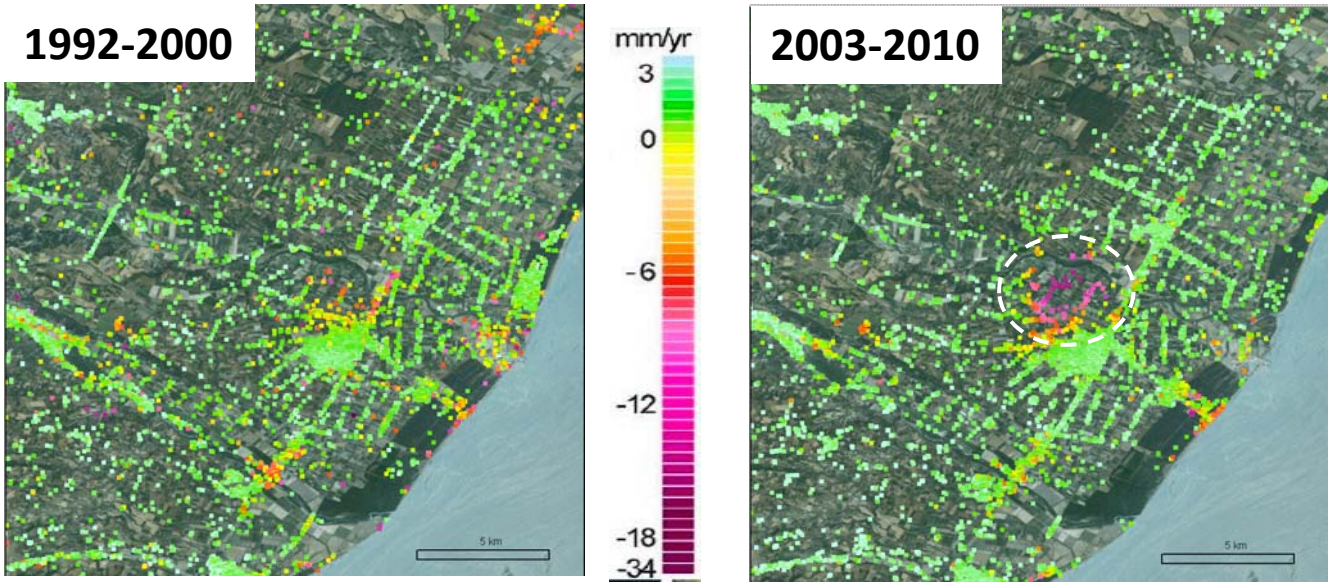


Subsidence rate has significantly increased with the post-war economic growth and the **pumping of groundwater by industries and with the rise of tourism activities** along the coastal areas.

Southern Italy - Calabria Region: Policoro



The subsidence induced by **gas exploitation** is localized in a restricted area of about 0.5 km radius



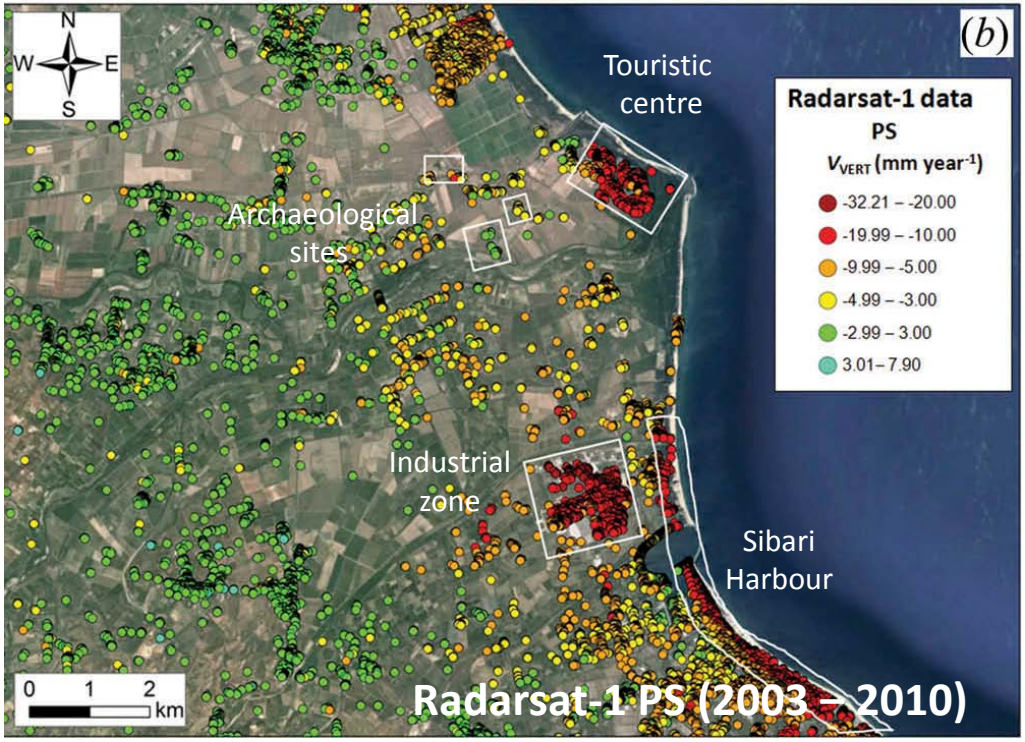
Southern Italy - Calabria Region : Sibary plain

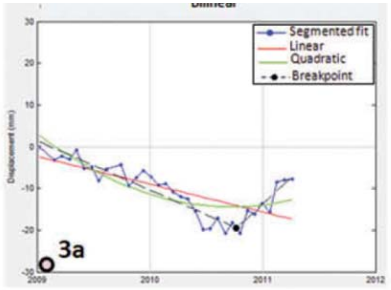
International Journal of Remote Sensing, 2015
Vol. 36, No. 18, 4550–4569, http://dx.doi.org/10.1080/01431161.2015.1084433
Taylor & Francis

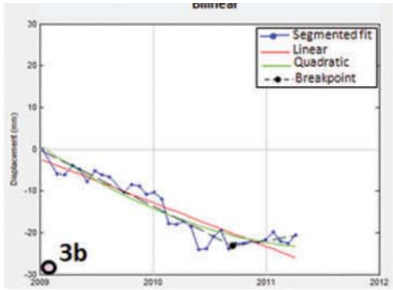
Analysis of recent ground subsidence in the Sibari plain (Italy) by means of satellite SAR interferometry-based methods

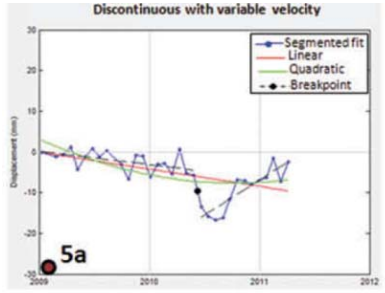
Silvia Bianchini* and Sandro Moretti

Department of Earth Sciences, University of Florence, 50121 Florence, Italy







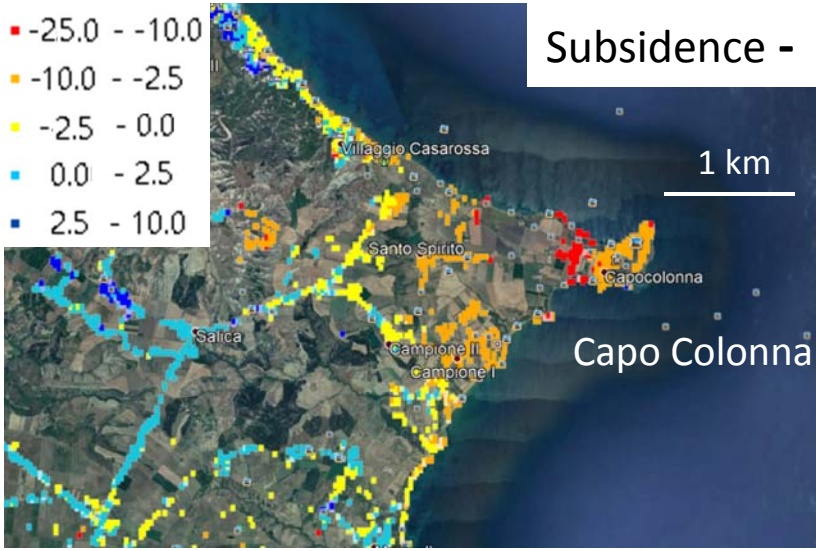


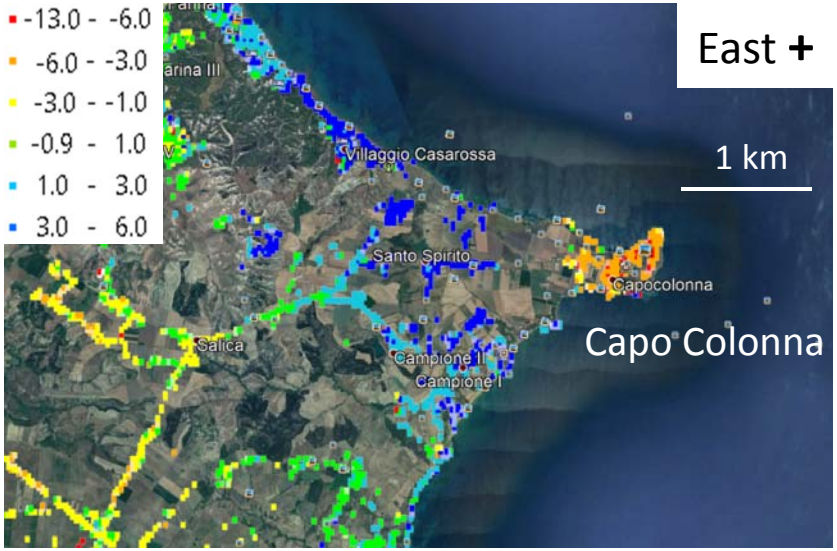
Localized high subsidence rates induced by **groundwater exploitation in nautical and residential centers and in the Industrial Zone**.

A detailed analysis of the evolution of the displacements time series points out that the subsidence has positively decreased or stabilized from the second semester of the year 2010.

Southern Italy - Calabria Region : Crotone

The maximum vertical movement are detected at Capo Colonna in the area surrounding **gas exploitation** wells.
Toward the inland, the displacement trend decreases.
Notice that the ground displacements induced by gas exploitation, although localized are significantly high also in the W-E direction.





Southern Italy - Campania Region: Gioia Tauro plain

Journal of Maps
Vol. 8, No. 4, December 2012, 514–524

Multi-temporal mapping of land subsidence at basin scale exploiting Persistent Scatterer Interferometry: case study of Gioia Tauro plain (Italy)

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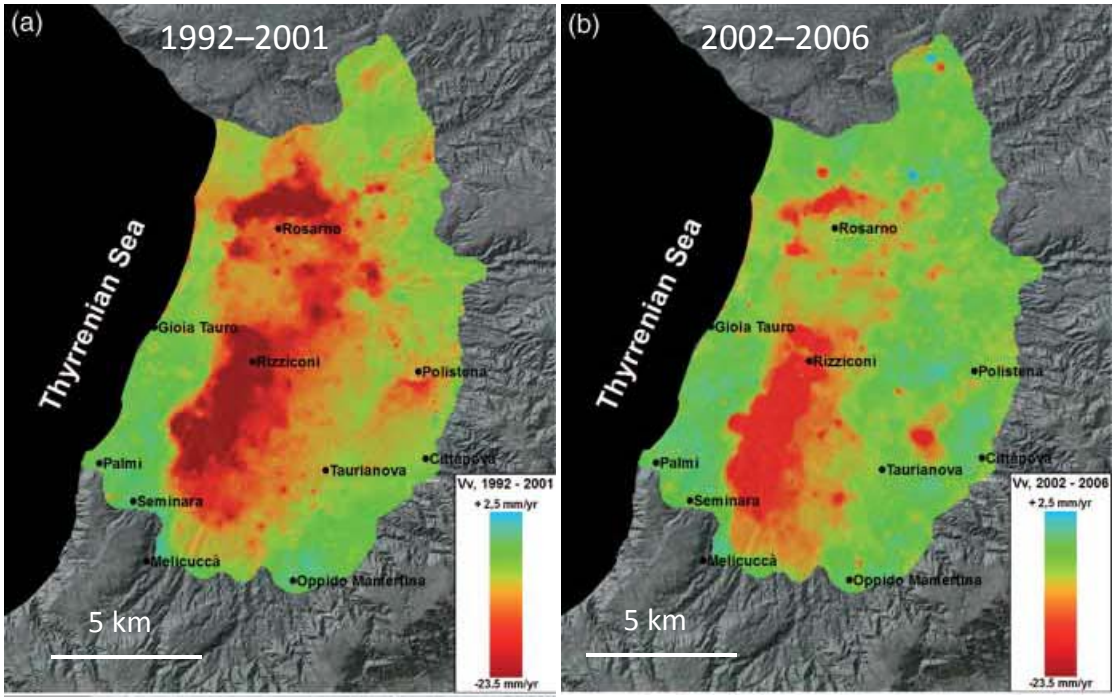
[a]*Department of Earth Sciences, University of Firenze, Firenze, Italy;* [b]*British Geological Survey, , Nicker Hill, Keyworth, Nottingham, UK*



Land subsidence involves a fairly wide area in the Gioia Tauro plain.

The aquifer compaction is a consequence of **huge groundwater abstraction**.

A general deceleration of motions is observed in most of the plain with velocity reductions of about 65% from 1992–2001 to 2002–2006
Only in the Taurianova area a new land subsidence bowl has appeared in the second period.

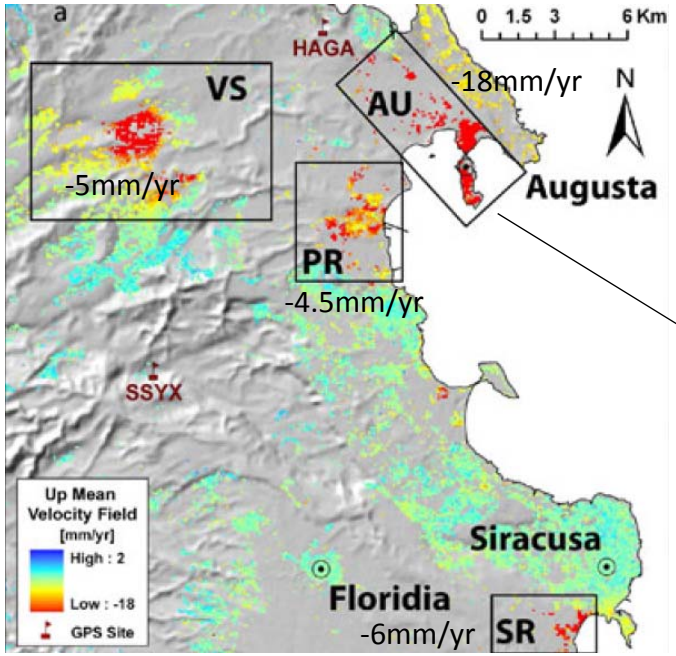
Southern Italy - Sicily Region: Augusta, Siracusa, Villasmundo, Priolo

EARTH SURFACE PROCESSES AND LANDFORMS
Earth Surf. Process. Landforms 37, 273–286 (2012)

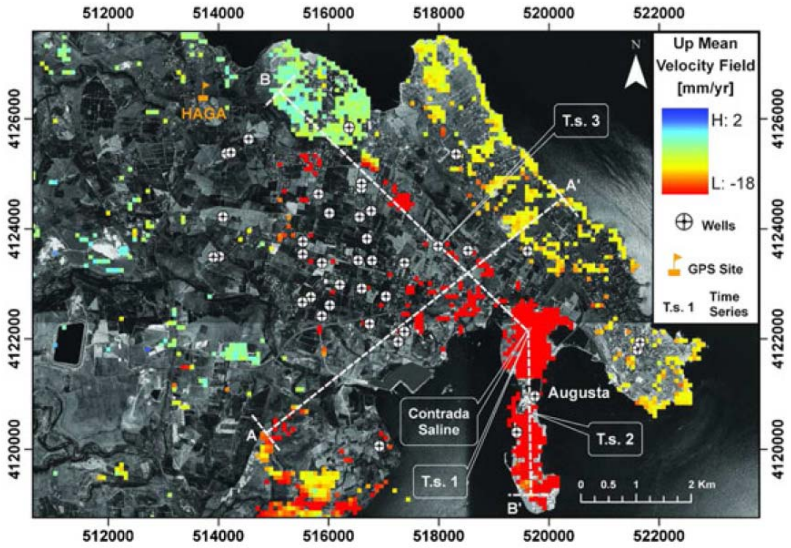
Published online 14 October 2011 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/esp.2238

Land subsidence along the Ionian coast of SE Sicily (Italy), detection and analysis via Small Baseline Subset (SBAS) multitemporal differential SAR interferometry

Fabio Canova,[1]* Cristiano Tolomei,[2] Stefano Salvi,[2] Giovanni Toscani[1] and Silvio Seno[1]
[1] Dipartimento di Scienze della Terra e dell'Ambiente, Università degli Studi di Pavia, Pavia, Italy
[2] Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italy



Local land subsidence occurred also along the Ionian coast of the Sicily: Augusta (AU), Siracusa (SR), Villasmundo (VS), Priolo (PR)



All the detected deformation patterns are primarily related to the **groundwater over-exploitation from several wells.**

Conclusive Remarks

Over the last decade, **a lot of new case studies emerged** mainly because of the development of **SAR-based interferometry** and the availability of free images from the **Space Agencies** and interferometric data from **National Geoportal of the Ministry of the Environment and Land and Sea Protection**.

The new cases of land subsidence presented here today are certainly not complete, and some other sinking areas were not included. However, this presentation provided an **overview of the land subsidence areas in Italy quite exhaustive**.

SAR Interferometry allowed to investigate the subsidence process in areas never been studied before.

Advantages:

- A much wider and accurate quantification (space/time) of ground dynamics.
- An improvement on the various factors driving land subsidence for the “historical case studies”.
- Increased the awareness that subsidence is a widespread process acting both at regional and local scale.

Disadvantages:

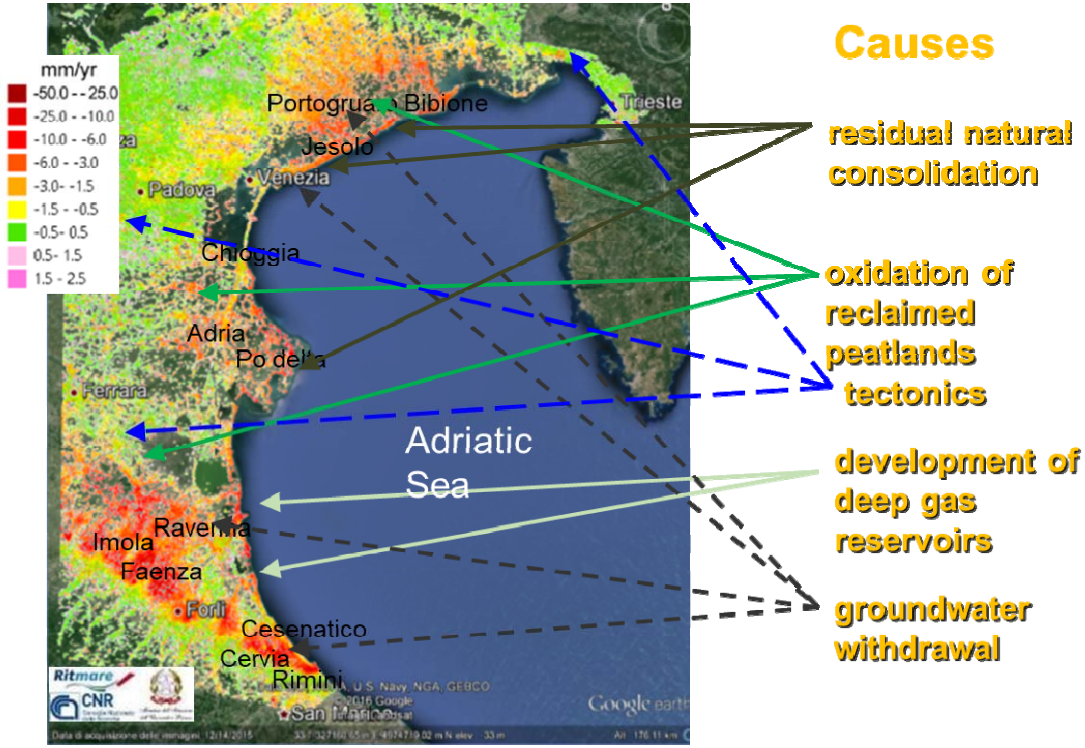
- Much more monitoring applications “only” than in-depth studies really improving the process knowledge (e.g., lack of aquifer and subsoil characterization).

Conclusive Remarks

Land subsidence is a great concern particularly in the low-lying areas already facing sea level rise due to climate change. **Today the most extend sinking area in Italy is still the northwestern coast of the Adriatic Sea**.

Detailed SAR-derived subsidence maps allows implementing targeted measures for mitigating and preventing the effects of land subsidence, such as:

- Regulation of groundwater extractions
- Management plans for hydraulic drainage of low-lying areas
- Best practices for irrigation
- Coastal protection works
- Vulnerability assessments



Thank you