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Integration of geodetic observations and geological models for investigating the permanent component of land subsidence in the Po Delta (northern Italy)

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   - 1.2 Land subsidence
2. **Multi-component and multi-source approach for studying subsidence in deltas:**
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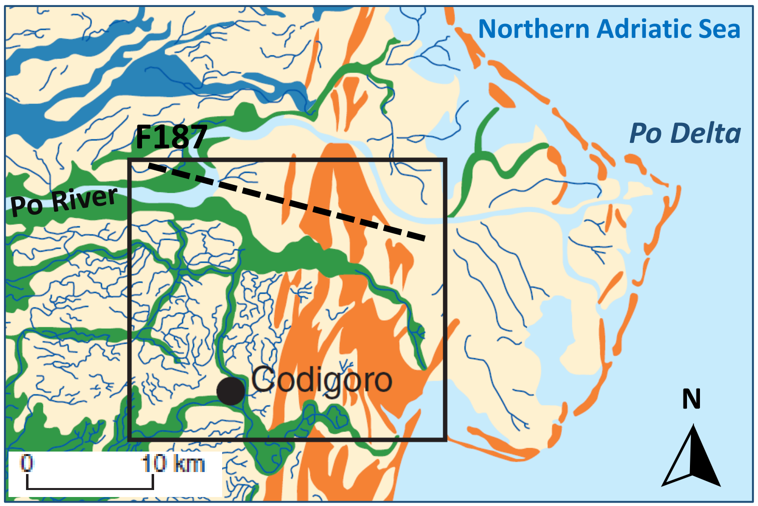
4. **Integration between geodetic data and modelling**
5. **Conclusions**

1. Po Delta Area (northern Italy)

1.1 Geology

Geological map of Po River Delta



Modified from Geological Map of Italy (1:50000)
F. 187 - Codigoro (Geological Survey of Italy, 2009)

MAP LEGEND
- Ancient coastal sands and delta front (orange)
- Inter-distributary bay deposits of lower delta plain (light-yellow)
- Distributary channels of the Po (green) and Adige (blue) Rivers
- F. 187 outline (black square)
- Modelled section (dashed black line)

Po River Delta is characterized by lower delta plain, with ancient coast, delta fronts and lagoons constituted by inter-distributary bay deposits, marsh deposits, beach-ridge, and aeolian dune sediments (Correggiari et al., 2005).

The delta plain overlays 10–30 meters of deltaic, littoral and marine sediments, deposed during the last Holocene prograding phase (Geological Survey of Italy, 2009).

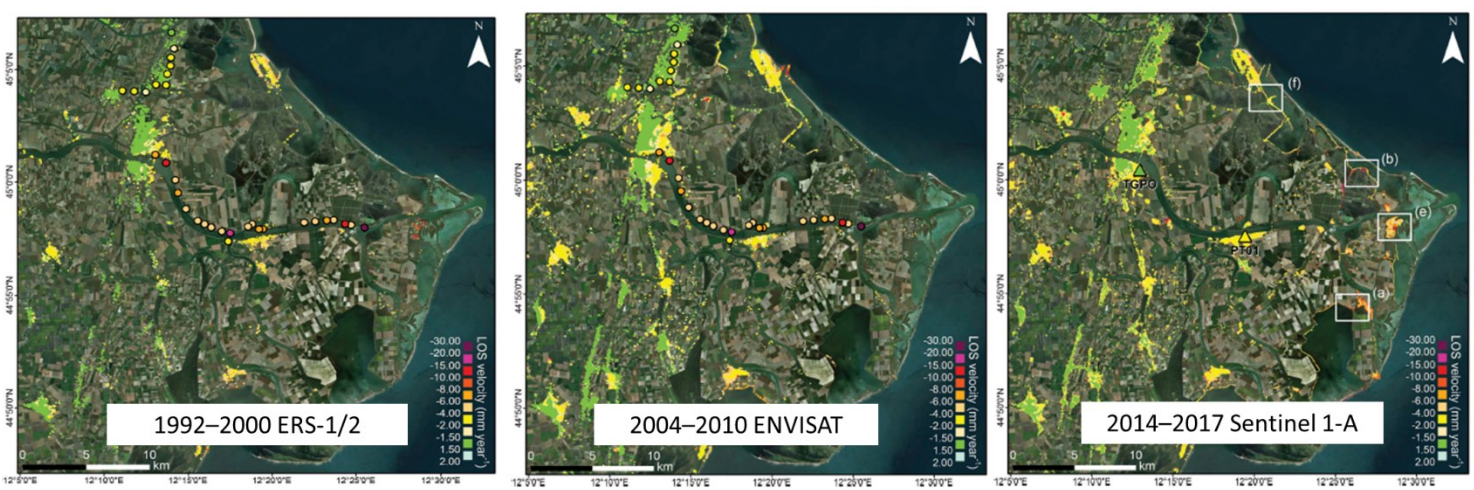
1. Po Delta Area (Northern Italy)

1.2 Land subsidence

Largest land subsidence rates in the Po Delta area have been measured by levelling during the period 1950–1957, when Delta was subjected to an intense phase of methane extraction from the relatively-deep aquifers. In 1960, production wells were closed and ground lowering rates diminished.

Over the last few decades, advent of space geodetic techniques for monitoring the Po River Delta and near coastal areas, such as GNSS and DInSAR, and integration among different tools, favoured a more complete observation of the subsidence phenomenon.

So far, present day subsidence rates are found ranging from 2 to 5 mm/yr in the central part of the delta, while they increase in the eastern sector, reaching 10–12 mm/yr, corresponding to the Po River mouth, and up to 30 mm/yr in proximity of littoral zones.



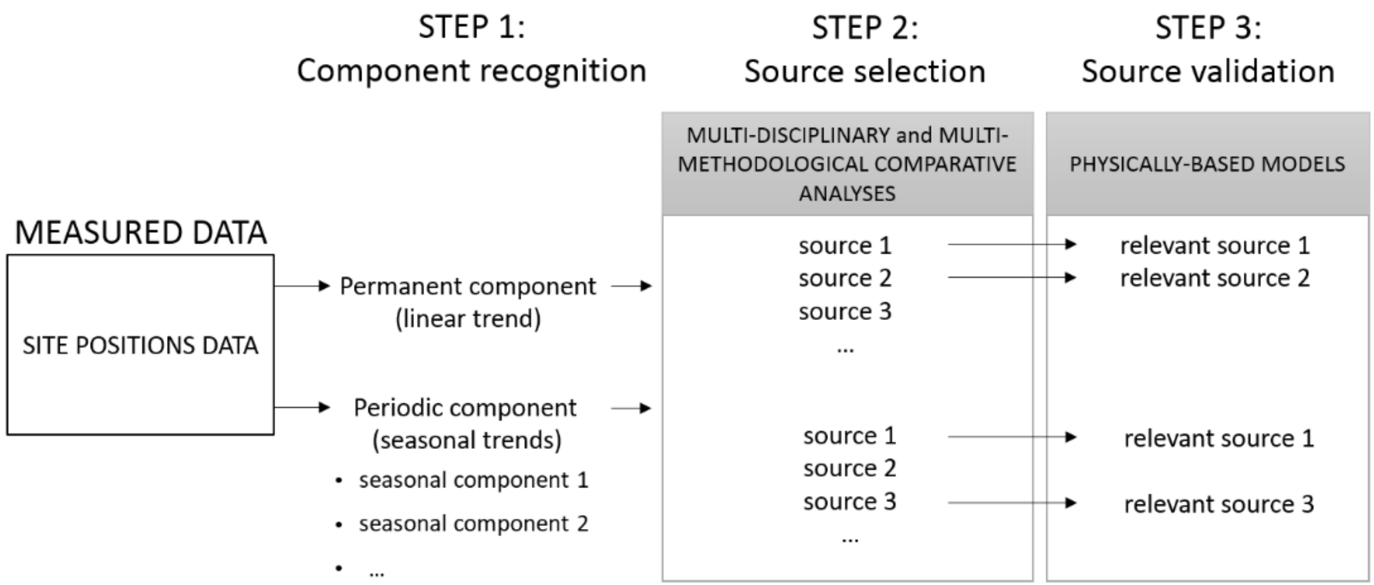
Example of velocity maps along the LOS obtained by using satellite surveys

Modified from Fiaschi et al., 2018

2. Multi-component and multi-source approach

2.1 Methodology

The used approach detects physical mechanisms that better explain permanent and periodic components of subsidence observed in the geodetic time series



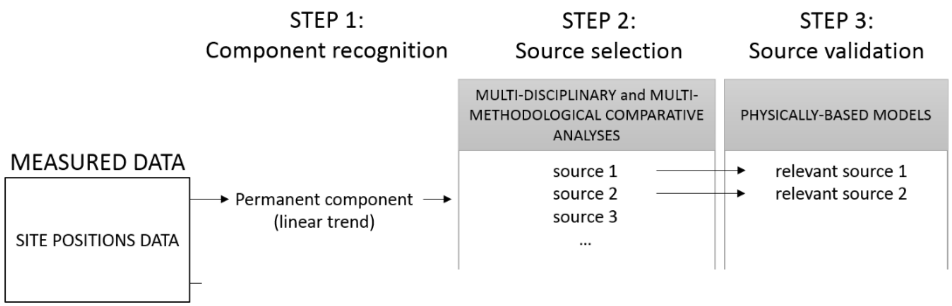
Vitagliano et al., 2020

Steps:

1. Component recognition, based on statistical and spectral analyses of geodetic time series
2. Source selection, based on comparison between geodetic dataset and data of different nature
3. Source validation, where the selected sources are validated through physically-based models

2. Multi-component and multi-source approach

2.2 Application to Po Delta



Approach has been applied to retrieve permanent component of land subsidence

GEODETIC DATASET	STEP 1	STEP 2	STEP 3

GEODETIC DATASET

- 3 daily GPS time series: TGPO, PTO1 and CODI stations
- 2 weekly GPS time series: TGPO, PTO1
- DInSAR-derived time series: TGPO, PTO1, CODI, Albarella, Boccasette, Pila (Enel), Scardovari

STEP 1

Estimates of linear rates

STEP 2

Comparison between ground lowering rates and geological sequence thicknesses

Variable	CGPS SITE TGPO	PTO1	CODI	Coefficient of Determination R^2
CGPS linear rate[1] (mm/yr)	-3.4	-3.3	-1.7	
Plio-Pleistocene thickness[2] (m)	2450	2800	2800	0.6972
Late Pleistocene-Holocene thickness[3] (m)	28	36	28	0.8123
Late Holocene thickness[3] (m)	20	23	15	0.9401

Vitagliano et al., 2020

STEP 3

Geological Modelling for validating sediment compaction process in Holocene sequence

Best correlation seems to enhance compaction process of shallow sedimentary layers

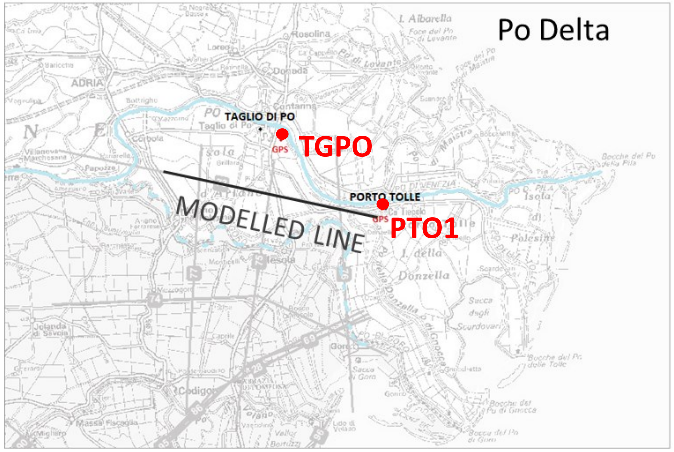
3. Geological modelling

3.1 Model layers and subsidence rate computation

Modelled line comprises 10 horizons dated from 18000 years (18 kyr) before Present; it simulates continuous depositional events (not erosive events) and one hiatus between 11 and 14 kyr. The layer geometry has been built by merging the horizons depicted in the geological sections AA' and CC' belonging to the shallow and deeper sheets of the Geological Maps F187 (Geological Survey of Italy, 2009). The litho-types and the petrophysical properties have been associated in accordance with literature (e.g., Cibin & Stefani, 2006) and lithology of boreholes.

Subsidence rates has been calculated according to back-stripping procedure and introducing paleo-water depth and paleo-sea level corrections.

Base Map



Location of modelled line and continuous GPS Stations: Taglio di Po (TGPO) and Porto Tolle (PTO1)

Modelled layers

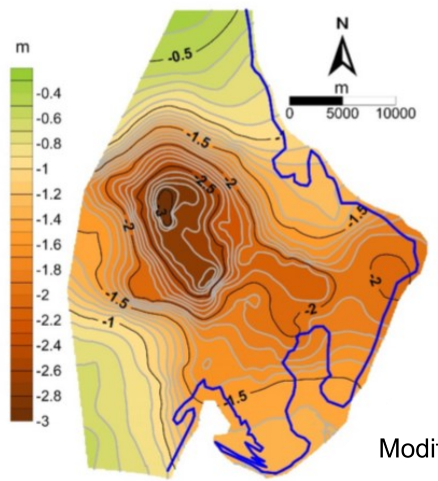
LAYER	TOP HORIZON
9	Topography
8	AES8-AES8a Boundary
7	Prograding surface 3
6	Prograding surface 2
5	Prograding surface 1
4	Base of prograding system
3	Maximum floading surface
2	Base of retrograding system
1	Top alluvial deposits

4. Integration between geodetic data and modelling

I. Applying multi-component and multi-source approach

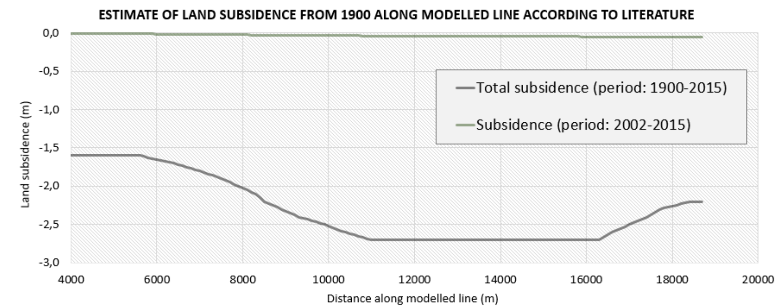
II. Restoring model topography

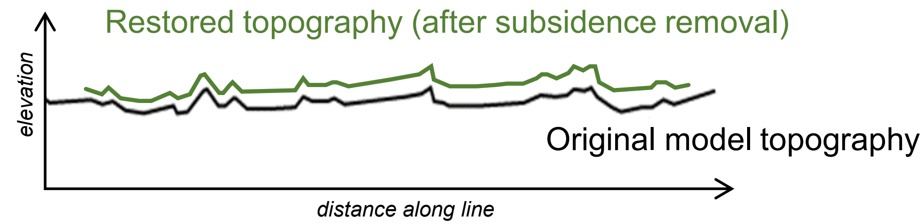
Cumulative land subsidence



Map has been obtained by levelling and satellite surveys and is referred to 1900-2015 period

Modified after Corbau et al., 2019





III. Comparing observations with model findings

Maximum computed subsidence rate

Location	Rate	LOS Rate
TGPO projected	-0.8 mm/yr	-0.6 mm/yr
PTO1 projected	-1.6 mm/yr	-1.3 mm/yr

Results are affected by uncertainty on model input (geological data)

LOS velocity values*

Location	LOS velocity CGPS	LOS velocity Sentinel-1A
TGPO	-1.3 mm/yr	-1.9 mm/yr
PTO1	-2.7 mm/yr	-3.1 mm/yr

*Values from Fiaschi et al., 2018

5. Conclusions

- ✓ A multi-component and multi-source methodology has been applied for studying the permanent component of land subsidence in Po Delta
- ✓ Geodetic data have been used for restoring model topography and identifying relevant source of land subsidence in the central part of Po Delta
- ✓ Comparative analysis shows that the best correlation occurs between Late Holocene sequence and geodetic observations and suggests occurrence of sediment compaction mechanism
- ✓ Geological modelling partially validates this process, but modelling is also affected by great uncertainty about geological data used as input

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