VERTICAL MOVEMENTS IN THE GRADO LAGOON (ITALY) MEASURED WITH VARIOUS METHODS

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Abstract: The lagoons of Grado and Marano, in the northeaster part of the Adriatic Sea (Italy), are subjected to vertical displacements, generally the height of the area is decreasing respect the mean sea level (subsidence). Starting from 1980 in the area around and inside the lagoons some geometric levelling lines was installed and measured. In several parts reciprocal trigonometric levelling was used to connect together the islands. Around every 6 km of levelling lines was performed GPS measurements, beside them gravimetry (every 3 km) and deflection of the vertical (every 24 Km) were measured.
During 2004 and 2005 the whole levelling net was measured with the above mentioned instruments and the levelling line was extended to the Trieste tide gauge. The accuracy of the geometric levelling was normally less than 1 mm/km^{½}. The comparison between the levelling heights of the different epochs, related to the actual mean sea level, measured in Trieste, confirms the general subsidence of the lagoon area. Along three lines this behaviour is greater: in a part of the road inside the lagoon of Grado and on two islands, the greatest difference is 18 cm in 24 years. In this last area a third measurement was performed in order to confirm this behaviour.

1. Levelling network

The lagoons of Grado and Marano, in the northeaster part of the Adriatic Sea (Italy), are subjected to vertical displacements, generally the height of the area is decreasing respect the mean sea level (subsidence). To control this phenomenon a levelling network was installed (Fig. 1).
The Italian national geodetic body (IGM) have rebuilt and measured in 1952 the line 34 of the Italian first order levelling network. We consider here the stretch from Latisana to Ronchi, from here the IGM line Cj (1956) reaches the tide gauge of Trieste. These lines were remeasured in 1977, 1980, 1989, and 2002
The public water authority in Venice (UIMA) have installed and measured in 1980 four lines, from the IGM 34 line to the Adriatic coast at Lignano (UIMA A), Marano (UIMA 8), Grado (UIMA 7) and the mouth of the Isonzo river (UIMA 3). Beside them a line follow the coast line from Isonzo to Grado (UIMA 3) and from Grado to Lignano (UIMA6) through a chain of islands with several trigonometric levelling lines, generally the distances are less than half km. In this case the accuracy of the reciprocal trigonometric levelling is not too much higher respect the geometric one.
A densification of the network was performed in 1989 by the regional administration of Friuli-Venezia Giulia (FVG), with new points in the existing lines and with new lines.
During the 2004, sponsored by the Civil Defence of the Region FVG, all the UIMA and FVG lines were remeasured, with an accuracy normally less than 1 mm/km^{½}.
The comparison between the levelling heights of the different epochs, related to the actual mean sea level, measured in Trieste, confirms the general subsidence of the lagoon area.
In same areas this behaviour is greater, so a third measurement was performed in order to confirm this behaviour.

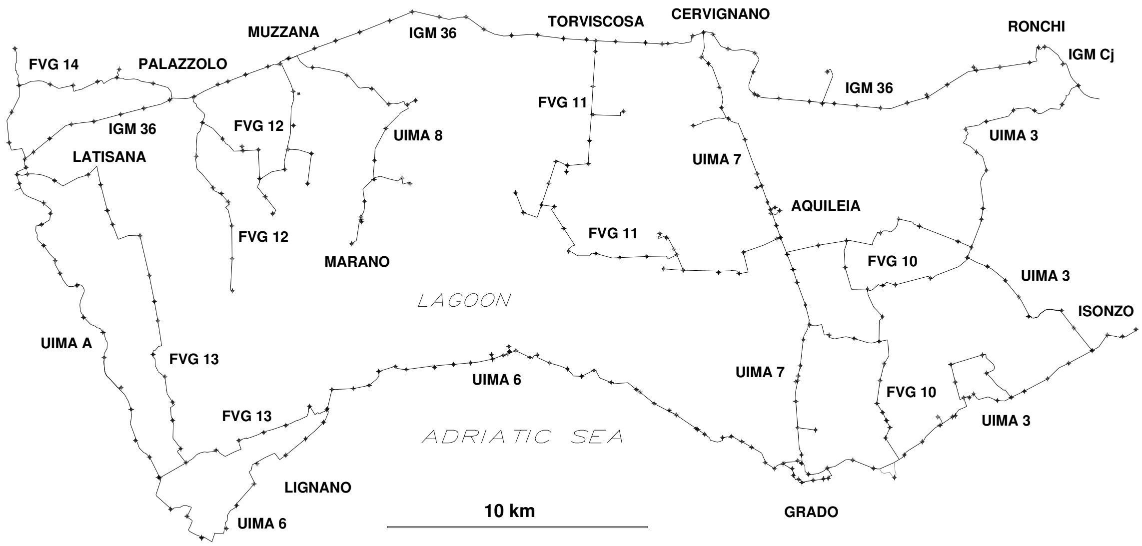

Figure 1: Levelling network of the lagoons of Grado and Marano

2. Reference for the heights

From 1890 a tide gauge is active without interruption in the harbour of Trieste, that gave the height reference for the former Austrian-Hungarian Empire.
The annual mean sea levels (fig. 2) are referred to the benchmark IGM Cj 39, positioned on the peer.

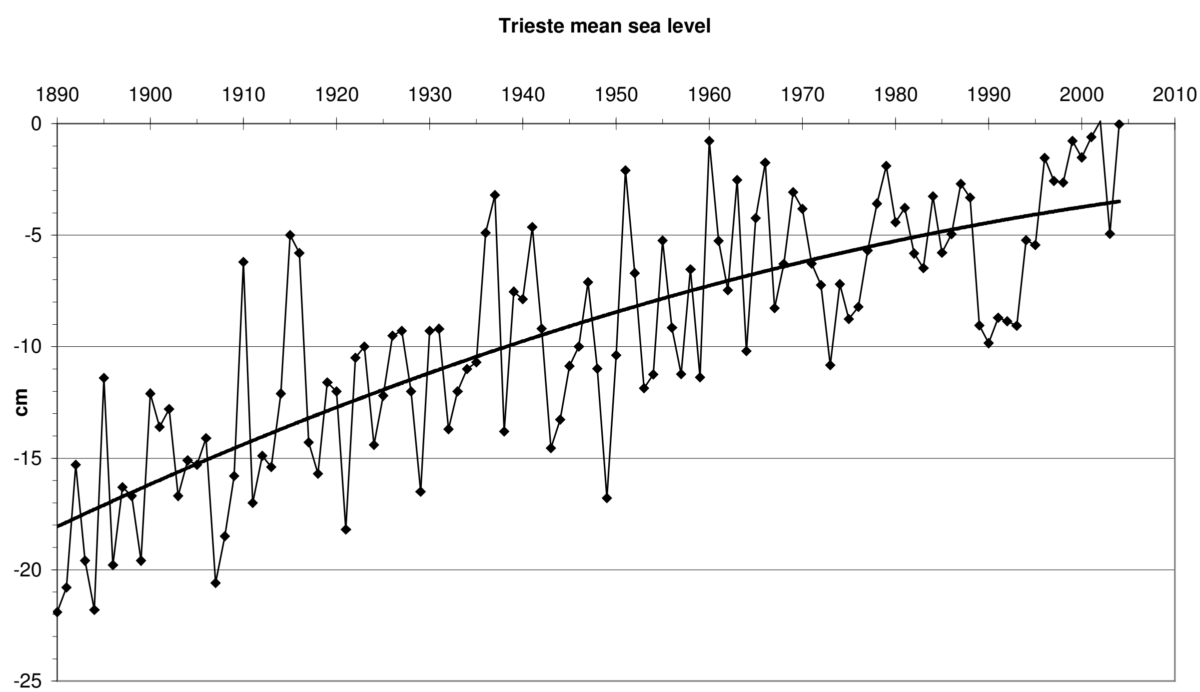

Figure 2. Variation of the annual mean sea level measured at the tide gauge of Trieste with polynomial regression, after F. Stravisi [1]

As local reference for the heights we choose in every measurement epoch (1980, 1989 and 2004) the actual value of the polynomial regression. The use of a reference changing in the time is theoretically not correct, but I think is the more suitable to areas situated al the sea level. The later mentioned displacements include both the terrain subsidence and the sea level rise.

3. Line UIMA 7 (Cervignano – Grado)

The levelling line UIMA 7 starts from Cervignano, in the middle of the lower Friuli plain, and reaches Grado, at the sea after 19,5 Km along the state road 352, crossing from North to South. The stretch from Terzo (3,9 Km from Cervignano) to Grado was remeasured also in the 1997, by G. Zambon [2].
We consider the vertical displacements from 2004 to 1997 and to 1980.

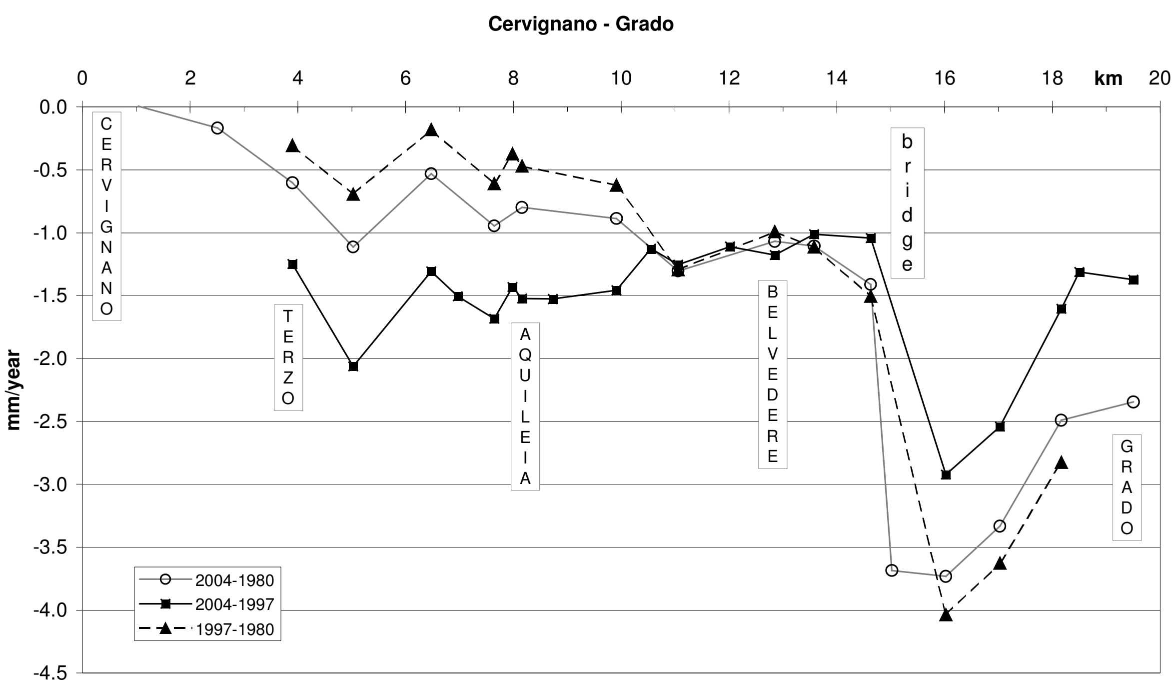

Figure 3: Vertical displacements per year of the levelling line Cervignano - Grado

From Cervignano to Grado the subsidence is increasing, but immediately after the bridge of Figariola (1 km from the border of the lagoon) we have a suddenly increasing of the lowering. The benchmarks are situated on the road embankment, which was settled at the end of the 19th century during the Austrian-Hungarian rule with the material dredged from the lagoon to excavate the adjacent channel. The different behaviour seen in fig. 3 is related to the different type of material: most sand northern of the bridge and most clay in the south. Near Grado we have again more sand.
The increasing in the time of the subsidence annual rate in the lower Friuli plain, from Terzo to Belvedere can be connected with the increased water exploitation in this area. At the contrary in the lagoon area, from Belvedere to Grado, the annual rate is decreasing.

4. Line UIMA 3 (Grado – Primero)

The levelling line UIMA 3 from Grado to Monfalcone was remeasured in the 2005 only in the stretch most interested by the subsidence, i.e. from the eastern border of Grado to Primero. Students of the Udine University performed the measurements as fieldwork [3].
In the old times the interested area was partially lagoon and it was drained in the twenties of the last century. The here considered stretch starts from western border of the Grado island, travels toward east, parallel to the coast, until Primero, then follows the coastal bank in direction north-east until the mouth of the Isonzo river, totally 17 km. The last benchmark lies on the on the other side of the river, consequently a 0,5 km long reciprocal trigonometric levelling was used.
The annual rates of the vertical displacements were depicted in Fig. 4.

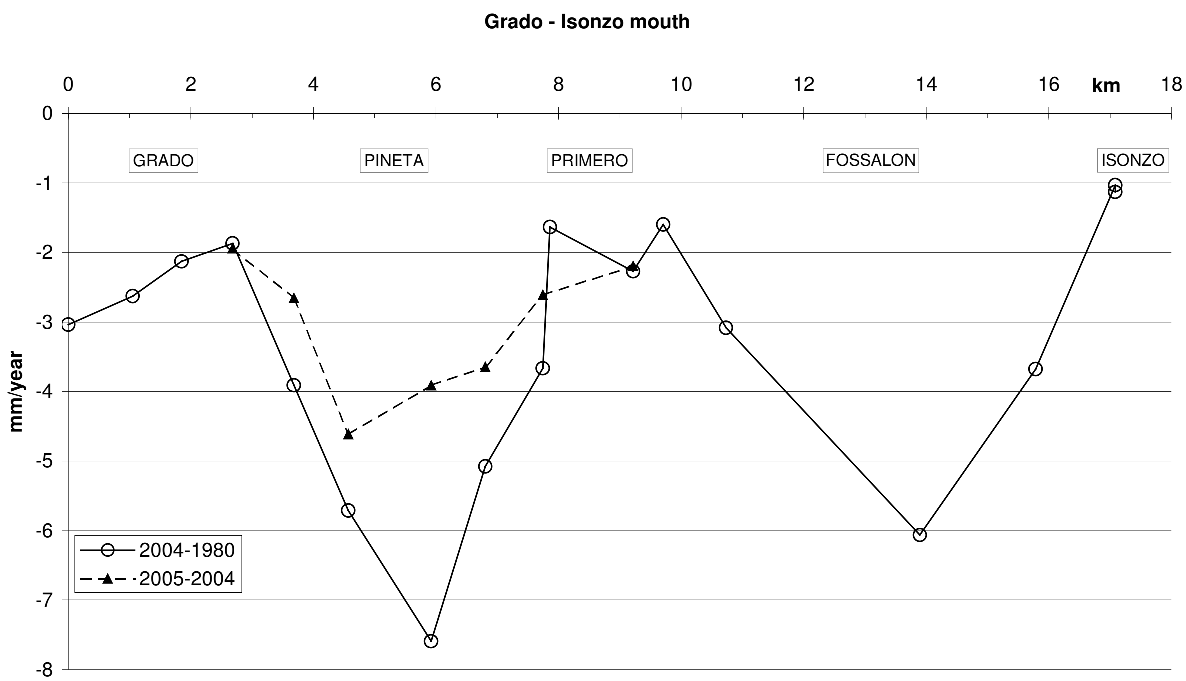

Figure 4: Vertical displacements per year of the levelling line Grado – Isonzo mouth

The two areas, Pineta and Fossalon, with most important subsidence coincide with the drained areas; the values of annual rates are substantial greater respect a normal value for a lagoon (1 ÷ 2 mm/year). The third measurement was executed only after 22 months, but the differences with the previous one are clearly visible. As the lagoon part of the line UIMA 7, also here the subsidence annual rate is decreasing in time.

5. Lagoon of Grado East

On the islands Valle del Moro and Barbana in the eastern part of the Grado Lagoon two benchmarks was installed and measured in the 1989 and remeasured in 2005.

The benchmark Valle del Moro is a 690 m long deviation of the line UIMA 7, with an intermediate station.

The subsidence annual rate of -3.18 mm/year is similar to the neighbouring point of the principal line (-3.33 mm/year).

The island Barbana lies in the middle of the lagoon and is crossed by the line FVG 10, lagoon branch, which connects the northern and southern border of the eastern part of the Grado lagoon. From the land (north) to Barbana 3 intermediate stations are necessary, total length 1545 m; from Barbana to south (island Grado) with other 3 stations, total length 1485 m, we reach the land, finally with 1 Km levelling stretch we arrive to the line UIMA 3.
The subsidence annual rate of Barbana (-3.75 mm/year) is lower respected the initial (-5.13 mm/year) and final point (-7.59 mm/year) of the trigonometric line.

6. Other types of measurements

In occasion of the last levelling measurement (2004), to understand better the phenomenon of the subsidence, other type of measurement were performed with the co-operation with G. Poretti of the Trieste University and students of the Udine University.
All the following measurements were performed for the first time in this network; consequently we do not have comparisons with previous values.
The GPS network follows the levelling net with a station around every 6 Km. In two sessions of each 7 hours, in total 17 points were measured connected with 2 permanent and 2 epoch stations.
With a portable gravimeter a third of the levelling benchmarks were measured in more times, but with reference with the absolute gravity station of Trieste.
The deflection of the vertical was measured every 24 Km, using the star observation with a theodolite and GPS timing.

7. References

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