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Extreme events in Italy from documentary sources: Venice as a case study(*)

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Summary. — Venice risks to be submerged as a consequence of two problems: local land subsidence and sea level rise due to global warming. They both contribute to what is referred as Apparent Sea Level Rise (ASLR). Flooding Tides (locally: Acqua Alta) submerge Venice with an exponentially increasing frequency. The Acqua Alta is generated by a number of factors, the main of them being the Sirocco wind blowing over the Adriatic Sea, that ultimately displaces waters towards Venice. These extreme events have been investigated by using the documentary description of past floods, accurately reported over the last millennium, and tide gauge records for the recent period. A fundamental problem is to know the trend of the ASLR, possibly distinguishing between land subsidence and sea level components. Instrumental data go back to 1872 and a key point is to extend our knowledge back in time. Long-term ASLR has been investigated with the help of a biological indicator, *i.e.* the height of the green belt of the algae that live in the tidal range and whose upper front shows the average high tide level. Fortunately, in the first half of the 18th century, this indicator was accurately drawn by the famous painter Antonio Canaletto (1697-1768) and his pupils, mainly Bernardo Bellotto (1722-1780), in their *photographic* paintings made with an optical camera obscura. It has been possible to compare the tidal level, as it was in the 1700s and today. After careful spot investigation and minor corrections for some changes to the hydrological system occurred in the meantime, the bulk submersion of Venice estimated from the paintings is 61 ± 11 cm with average yearly trend 1.9 mm y^{-1}.

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1. – Introduction

Venices submersion has been partly due to the land subsidence, and partly due to the sea level rise in the Mediterranean. In the last three centuries, these two factors had the same order of magnitude, as we can deduce from independent evaluations of land subsidence [2, 3, 9-11, 14-16] and Mediterranean Sea level rise [17].

The Mediterranean sea level rise has been smaller than the known rate on the global scale for the following reasons: the Mediterranean is a nearly closed sea, with a small gate to the Atlantic Ocean, *i.e.* the strait of Gibraltar; in the last decades the precipitation in the catchment area has decreased and the evaporation increased [13], the balance with Black Sea has changed after the water of its tributaries has been extracted for irrigation purposes; and finally the atmospheric pressure has increased by 1 hPa which is equivalent to 1 cm sea level depression.

Both land subsidence and sea level rise contribute to what is referred as Apparent Sea Level Rise (ASLR).

Flooding Tides (locally: Acqua Alta) submerge Venice with an exponentially increasing frequency [5]. The flooding tides are governed by climate change (sea level rise and atmospheric circulation), meteorological triggers (Sirocco surges and air pressure field), land subsidence, sea surface oscillations (*seiches*), astronomical forces, anthropogenic factors.

The increasing frequency of surges has reached an unsustainable level.

A key point is to extend our knowledge back in time. These extreme events have been investigated by using the documentary description of past floods, accurately reported over the last millennium.

The first information we have relates to an event occurred at the end of the 8th century. That the problem existed from the early times of the history of the town, is demonstrated, *e.g.*, by a public speech of the Doge Pietro Ziani (1205-1229), trying to persuade its people to move in Costantinople, escaping from the frequent earthquakes and *acqua alta* submerging Venice. Of course he had political aims in emphasizing the situation, but the information confirms the antiquity of the phenomenon and of its impact on the life of the town.

This kind of sources gives an idea of the frequency and dimension of the phenomenon, but not precise measures. From one description of the event occurred in 1867, we can state that the subsidence of St. Mark Square since that year has been of 34 cm [12].

Tide gauge records have been used for the recent period. A fundamental problem is to know the long-term trend of the ASLR.

Regular instrumental measurements started in 1872, with continuous tide gauge records. These measurements show continuous fluctuations of the apparent sea level change, due to the actual sea level change and the combined effect of the soil subsidence, to which the atmospheric pressure adds temporary changes. During the instrumental period (1872-2000) the tide gauge measured a 31 cm rise which has been attributed in parts nearly equal to local subsidence (probably slightly dominant) and sea level rise.

Instrumental data go back to 1872 and a key point is to extend our knowledge back in time.

An analysis of the displacement of the height of the green belt of the algae that live in the tidal range and whose upper front shows the average high tide level shows the long-term trend of the apparent sea level rise so that is possible to obtain information concerning natural and recent anthropogenic contributions.

The phenomenon over the last three centuries has been investigated by using a proxy

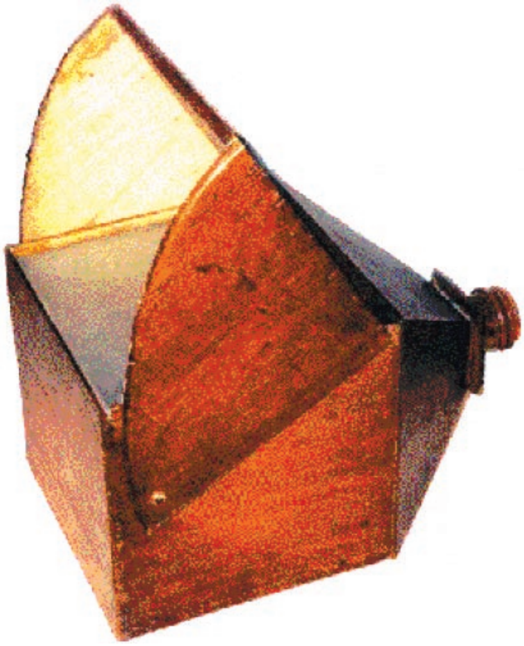

Fig. 1. – Canaletto's original camera (by courtesy of the Correr Museum, Venice).

of mean sea level: the height of the green belt of the algae, that live in the tidal range and its front indicates the average high tide level.

2. – Canaletto and Camera Obscura

In the first half of the 18th century, the green belt of the algae was accurately drawn by the Venetian painter Antonio Canal, nicknamed Canaletto (1697-1768) and his pupils, mainly Bernardo Bellotto (1722-1780). They made accurate reproductions of Venice buildings using a camera obscura (fig. 1) on the site.

The camera obscura, or *optica*, is an optical instrument, constituted of a box with a lens, similar to a modern camera, or a mobile tent model, which projects on to a sheet of paper the image of the view, so that the artist can carefully draw all the contours. The light beam with the image of the view to be reproduced passes through an objective lens, is reflected by a mirror, and is projected onto a glass surface, where the artist places the sheet of paper, obtaining a photographic painting.

This instrument, mentioned by Leonardo, had a large diffusion in Italy through the Italian views (mainly of Rome and Venice) of the Dutch painter Gaspar van Wittel (Gaspare Vanvitelli) at the end of the 17th century. Canaletto derived this technique from his father, Bernardo, who was a scene painter. Before Canaletto, artists painting vedutas generally made a quick draft on the site, and then completed paintings in their workshops, including imagined details [6].

Canaletto and Bellotto paintings extend our knowledge about Venice submersion back in time for almost three centuries, which include the end of the Little Ice Age and the recent warming.

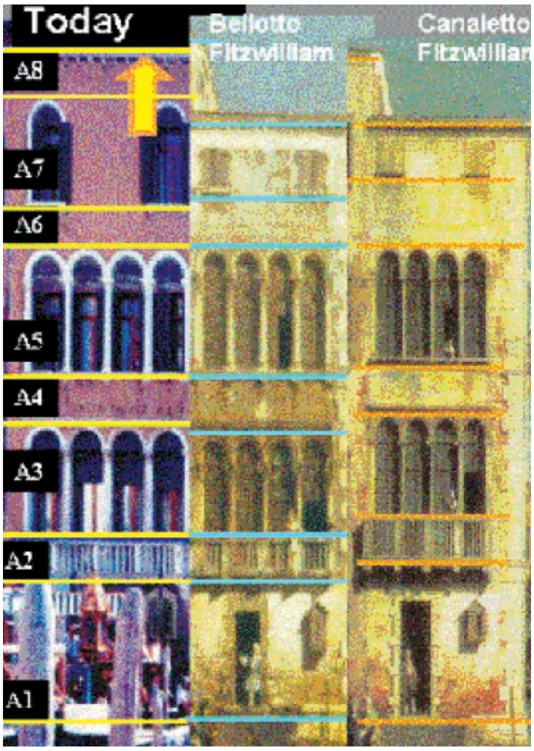

Fig. 2. – Example of the Standard Deviation methodology to assess the accuracy of the architectural features of the Pisani-Gritti Palace in Canaletto and Bellotto paintings. In the figure is reported the same view of two of the five different paintings of the lateral side of the Gritti palace (on the right) and the actual front side of this palace to better sign the strips.

3. – Analysis

Canaletto and Bellotto painted more than 200 paintings with views of Venice.

Our choice was restricted to twelve paintings which were considered the most reliable for this study (*e.g.*, visible algae belt, no reworked buildings).

The first step in our analysis is to check the painting accuracy in reproducing all details controlling two kinds of details: the architectural and decorative features of buildings and the pattern of the black crusts due to pollutants.

Another test is based on the cross-comparison between the size of the architectonic features as they appear in the painting and in a photograph of the actual building today. When dating is not available, to control the picture accuracy and following its reliability, also the standard deviation test is useful. This is obtained from the ratio of the size of the corresponding items and then calculating the standard deviation of each series, as follows.

For each painting, the building is divided into a number of strips corresponding to natural partitions of the facade, and the width of each strip is normalized expressing it as a fraction of the total building height (fig. 2).

The same is made with a picture of the building today.

Then the ratio is computed between each normalized size in the painting and the

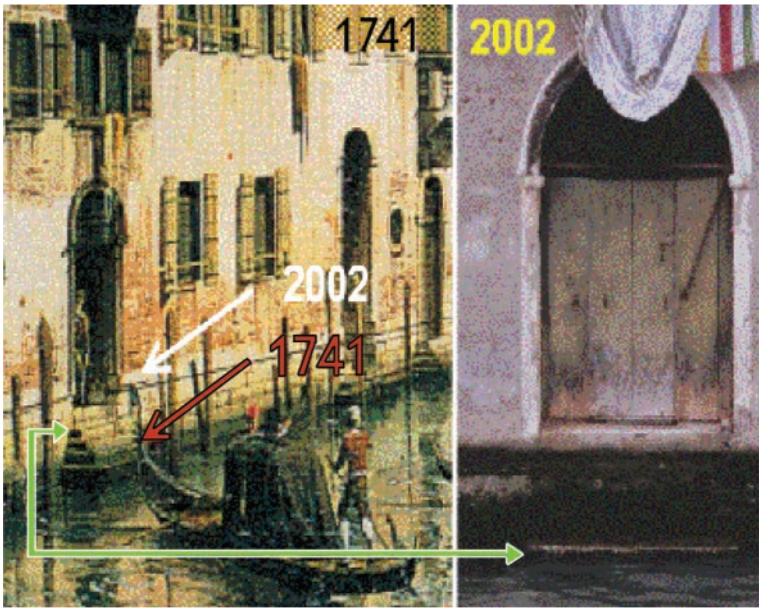

Fig. 3. – On the left: B. Bellotto, S. Giovanni e Paolo (1741), detail. The two arrows give the level of the algae belt in 1741 (lower) and today (upper) as derived from on the on-site observations. On the right: the same door nowadays, walled up in the lower part to avoid water penetration. The picture was taken during low tide and the first step is just visible. The painting shows that there were two steps above the green belt.

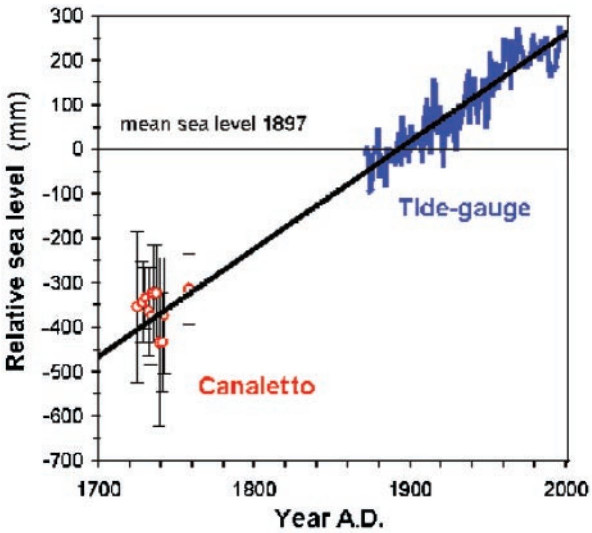

Fig. 4. – Apparent Sea Level Rise (ASLR) in Venice from tide gauges (continuous grey line, period 1872-2002), from Canalettos and Bellottos paintings (white dots with error bars, period 1727-1758). RSLR from paintings was estimated from the difference in level of the algae belt as it was in the paintings and as it is today.

corresponding size in the picture of the building today, obtaining values close to, but slightly different from 1.

It is finally possible to calculate the standard deviation of these ratios for each painting. The smaller the standard deviation, the better the accuracy. When a painting can be considered reliable and the algae belt occurs alongside recognizable details, it is possible to measure on the site how much the present day level is above that detail (fig. 3).

Computer image processing was useful to get a more precise evaluation of details in buildings affected by a perspective view.

4. – Results

From the analysis of the paintings the upper level of the algae belt, locally known as *Commune Marino* (CM), results to have been risen on average by Δ CMobs $= 69\pm11$ cm.

Part of the observed shift is not due to ASLR change. Waves generated by motor boats have a typical height of some 10 cm that is about twice the value for the 18th century row-boat traffic [4]. This is equivalent to an apparent 5 cm apparent CM rise, as estimated from wave observations in the Grand Canal under different traffic conditions.

After the excavations of two deep channels, the penetration of sea water into the Lagoon has been facilitated and the tidal wave has been amplified. This dynamical effect contributes to the yearly average tidal amplitude raising the CM for another 3 cm (tide gauge observations).

After these corrections, the bulk submersion of Venice estimated from the paintings is 61 ± 11 cm with average yearly trend 1.9 mm y^{-1} [7, 8] (fig. 4).

This finding is in agreement with the results obtained from archaeological evidence [1] from which 60 cm are obtained over the same period. The results obtained from this study are useful in view of deciding measures to save Venice and its historical buildings because they constitute a long-term observation of the local sea level rise.

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