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Considerations of lagoon hydrodynamics and currents in the inner canals of Venice: trends and open questions

The Venice Lagoon has been subject to erosion processes for some time, and these are profoundly modifying the most characteristic elements of its morphology. The processes are most evidently manifest by the widespread reduction in salt marsh cover, on the one hand, and generalised deepening of the water on the other - especially in the central and souther lagoon.

The causes can be found in the increased intensity of waves (*moto ondoso*) caused by wind and boat traffic and engineering interventions in the lagoon, especially construction of the long jetties at the inlets and dredging of large canals for navigation. The Malamocco-Marghera industrial channel has had the greatest impact, as shown by bathymetric studies comparing topographical surveys as well as theoretical investigations using sophisticated mathematical models.

The consequences are dramatic not only in terms of damage to the lagoon bed, that is being progressively eroded, but also to the network of canals in the city - canal banks and buildings along the canal margins.

Deeper water, compared to the past, has significantly increased the wave height of waves produced by wind action and therefore the energy carried by the waves. Consequently wave impact on the lagoon bed and building fabric is stronger.

Comparative studies of the historic lagoon and the current situation, published recently in some important international journals, clearly demonstrate increased intensity of erosive processes.

Also heavily negative in terms of erosion impacts are the waves generated by boats. For some typical lagoon vessels it has been shown that a fundamental parameter for limiting wave height depends on boat velocity, depending on the shape of the keel. So to limit wave height, and associated erosion damage, boat speed needs to be drastically reduced in the navigable canals, especially inside Venice. Unfortunately traffic controls and speed checks are not a strong feature of Venetian governance.

As regards ship traffic, damage to the lagoon bed due to erosion has been repeatedly shown and is confirmed by comparing the 1972 bathymetry with today’s. Regarding ships in semi-confined channels typical of the lagoon, particularly the man-made navigation canals, it is not only a question of moto ondoso (wake waves) but also the induced currents caused by the displacement of large volumes of water corresponding to the underwater keel, and when the canal width is similar to the keel, nearly all the water is pushed out of the channel as the ship passes.

Waves generated close to the ship are not normally very significant but as they propagate across the shallows they tend to get higher and break. Currents induced by displacement add their energy to these waves causing sediment resuspension and hence erosion in the areas adjacent to the channel. Only a fraction of this material is redeposited in the shallows while most are drawn by the currents that open in front of the ship’s prow and close behind it where they are deposited inside the channel.

The interaction effects of currents - waves - mobilised sediments are, from the point of view of these considerations, absolutely negative for the lagoon morphology and safeguarding the envrionment.

Some considerations of current velocities in Venice's canals

Since infrastructure works began at the inlets, for the past few years, significant changes have been noted in several places regarding current aspects around the city and along some inner canals. Unfortunately systematic monitoring of this (and other aspects) was not carried out by the institutions responsible for the works. Observations and sporadic current measurements have however provided significant indications. Important water flows have been registered in the south-north direction during incoming tides, below the railway and road bridges connecting the mainland and lagoon. These currents are stronger than before.

Changes in current direction have also been found in the inner canals of the Cannaregio sestiere, and seem to confirm shifts in "partiacque" between the Lido and Malamocco circulation basins, following interventions at the inlets. Load measurements at the node between the Grand Canal and Canareggio Canal carried out in Nov. 2011 (see Figs. 1 and 2 below) and general observations of current behaviour in nearby canals, show local modifications in current behaviour. This has impacts on sediment transport with non-positive effects on building foundations and other aspects of urban maintenance.

These films show current velocities in rio di San Marcuola, Venice.

https://youtu.be/2CGlzZfjFCg

https://youtu.be/1cNj0Fpyzfo

https://youtu.be/5RgXSNObz_k

https://youtu.be/4DeBQPnvJHM

From the figures it can be seen that when the tide is coming in, Cannaregio Canal receives water from the Grand Canal from both Rialto and the Train Station directions. When the tide is going out, the flow from Cannaregio Canal divides itself in both directions as well - towards Rialto and the Station. As a result, larger volumes pass through the Cannaregio Canal compared to the two branches of the Grand Canal with a higher velocity considering the narrower width of the canal itself. The water jet that forms when outflow into the Grand Canal is at its maximum is very perceptible especially for small row boats that are deviated by the strength of the flow.

The situation briefly described is very different from the survey carried out by Livio Dorigo in May 1962 ("Rilievi contemporanei di velocità della corrente di marea nei canali della Giudecca, Fondamenta Nuove, Canal Grande ed in alcuni rii interni della Città"). Fig. 3, taken from this publication, shows that current flow in Cannaregio Canal and the Grand Canal at Piazzale Roma (station 33 and 40 respectively) are the same, in contrast to what we find today.

Fig. 1 - Flow measurements at the intersection of the Grand Canal-Cannaregio Canal near San Geremia church, carried out on 26/11/2011 during a flow tide between 8.57 e le ore 9.06. In the three sections of the node, measurements are not simultaneous, hence continuity cannot be rigorously respected.

Fig. 2 - Flow measurements at the intersection of the Grand Canal-Cannaregio Canal near San Geremia church, carried out on 26/11/2011 during an ebb tide between 15.06 and 15.17. In the three sections of the node, measurements are not simultaneous, hence continuity cannot be rigorously respected.

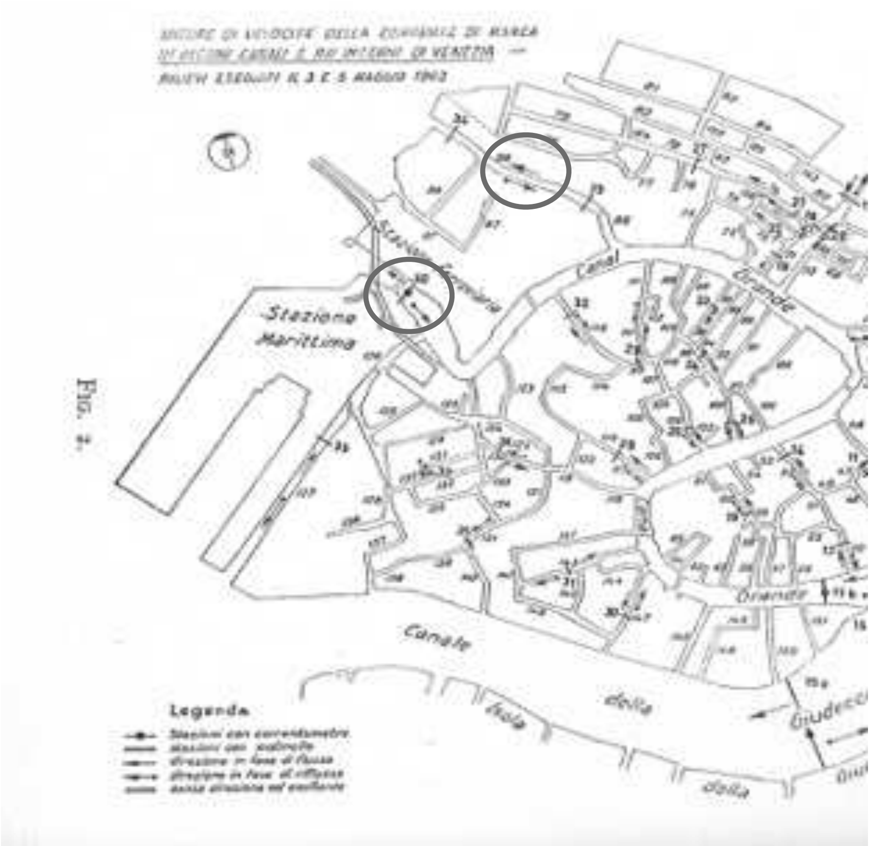

Fig. 3 - Measurements made in 1962 of tidal current velocities in the Giudecca Canal, Fondamenta Nuove, Grand Canal and some inner canals. Istituto Veneto di Scienze Lettere ed Arti – Venezia 1966.

In the 1990s, inversion of the flow in the section of the Grand Canal between San Geremia and Tronchetto had already been detected. The CNR Report “Misure correntometriche in Canale Grande (14 gennaio – 1 febbraio 1991)” notes that during ebb tide the current around the Train Station flows towards Tronchetto, in contrast to the ebb flow at the other two sites (near S.Angelo and at S.Maria del Giglio) which goes directly towards San Marco.

As already said, this phenomenon has intensified over the past decade especially, but there is not enough data to objectively reconstruct the trend.

Ideally the phenomena described above - inversion of flows and increased current velocity - would be monitored via an extensive and systematic campaign of simultaneous readings of water level and loads to get empirical confirmation of this phenomenon and its extent.

The increased intensity of the current against the canal banks and buildings, along with the effects of waves generated by boat traffic, could contribute to widespread structural weakness. Walls and banks are not impermeable and the pumping action in-between the building components (bricks, stones) carries away the fine sediments leaving open cavities of different dimensions that could ultimately lead to collapse.

Analysis of water level readings: 1989 to 2014

Possible changes to tidal current regimes in the Lagoon, especially around the historic centre following the start of works on the tidal barriers at the inlets, need to be verified and monitored via dedicated measurement campaigns with current-metres.

As a preliminary step, some interesting evaluations can be made using readings from the tide gauge network in the Lagoon, managed by ISPRA's Venice Lagoon Service. Water levels are indeed the main "forcing" for lagoon currents, hence variations in amplitude and phases of oscillations in water level at the various stations in the network can be considered reliable indicators, albeit indirectly, of variations that have taken place and are underway as regards tidal current regimes in the Lagoon.

ISPRA Venice Lagoon Service data processing was used for this purpose, with relation to a series of stations located at the inlets and in the Lagoon over the period 1989 to 2014[1]. Data elaborations provided are preliminary and are part of ISPRA's analysis and reporting services to monitor tidal and average sea level trends (ISPRA - Annual Environmental Data: http://annuario.isprambiente.it/ada/scheda/5767/13, http://annuario.isprambiente.it/ada/scheda/5766/13)

The above-mentioned analyses provide, yearly and for each station, the so-called "harmonic constants" of the tide, i.e. parameters that quantify the various components of the astronomic tide. Variations over time of the harmonic constants are particularly important because they indicate changes to the tidal regime that are not linked to transient climate variations but more significant changes like modifications to the morphological aspects of the lagoon basin.

According to the harmonic constants, the following can be determined on an annual basis:

- variation in the average amplitude of tidal oscillation in a generic point in the Lagoon
- variation in the delay in the phase of the tide at that point relative to sea-level or other points in the Lagoon

In this case, the gauges located at the three inlets (Chioggia, Malamocco and Lido) and the seven stations in the central lagoon, especially those closer to the historic centre, were taken into consideration (Fig. 4).

The graph in Fig. 5 shows changes in the amplitude of the astronomical tide from 1989 to 2014 for those stations. Data was obtained by combining the amplitudes of the seven tidal components.

Despite the irregularity of the curve and some missing data points, certain significant indications emerge albeit very preliminary.

In particular, the general tendency can be noted of substantial uniformity from 1989 to 2002, with progressive reduction in wave amplitude from 2003 at all the stations under examination except for at the inlets (dotted lines in Fig. 5).

This result suggests that in recent years tidal oscillation inside the lagoon has experienced some attenuation. This effect fits with the fact that interventions at the inlets have presumably increased hydraulic resistance to the tide as it passes through as a result of the insertion of fixed structures.

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[1] With thanks to Dr Marco Cordella di ISPRA – Servizio Laguna di Venezia, for permission to use the data in this analysis.

The graph in Fig. 6 shows, for the same stations and for the same time period, the time delay of the astronomic tide relative to sea-level. Data were obtained by calculating, for each year, the average of the phases of each component - weighted according to the specific amplitude of the respective component. Also here, the data shows some particularly interesting aspects.

To be noted is the relatively stable curve from 1989-2002, while from about 2003 the phase delays relative to the sea start to progressively increase. This trend is exhibited by all stations in the sample, except for at the inlets (dotted lines), where the phase delays stay essentially the same close to zero. The inference, as in the previous case, is that tidal propagation from the sea into the lagoon seems to have somehow changed in recent years. Greater delays at the inner stations also in this case seem to be attributable to greater hydraulic resistance to the current as it passes through the inlets, compared to the end of the last century.

Looking in detail, it can be seen that greater phase delays are found at Faro Rocchetta and Treporti, while much smaller increases are found at S. Nicolò and Punta della Salute.

These indications are particularly important as it is the differential in oscillations in water levels in different points in the lagoon basin that determine the intensity and direction of tidal currents. Since the data presented here show trends that are not homogeneous for all the stations, one can hypothesise that observed variations in current regimes in Venice’s canals can be tied to a “map” of phase-differences between the open waters around the city that have been modified in recent years [since works began on MOSE at the inlets]

Essentially, this data suggests firstly that eventhough the new architecture of the inlets seems to have generally increased hydraulic resistance, penetration of the tidal currents has been favoured more at the Lido inlet along the S. Nicolò canal, compared to the waters flowing in the direction of the northern lagoon along the Treporti canal. Secondly, the phase delay seems to have increased significantly between the Malamocco inlet and the internal waters (Faro Rocchetta station), indicating that new infrastructure at the Malamocco inlet has increased its hydraulic resistance more than in the case of the Lido inlet. If this were the case, the respective roles of the two inlets would have been modified as regards water supply to their respective circulation basins especially in the central lagoon. These effects could have had repercussions on the intensity of the currents around Venice as well as on the position of the “partiacque” that separates the circulation basins corresponding to each inlet.

To conclude, the very preliminary nature of the observations described above that require further and deeper elaborations that also include other stations in the tide gauge network of the Venice Lagoon.

Tide gauge readings, albeit very useful especially because of their availability over a long time frame, cannot alone supply quantitative and exhaustive indications of the hydrodynamic aspects considered here. More precise evaluations could be obtained with further examination of tidal currents at the inlets and around the historic centre of Venice - current measurements together with model based simulations and elaborations.

Fig. 4 – Tide gauge stations used for the analysis.

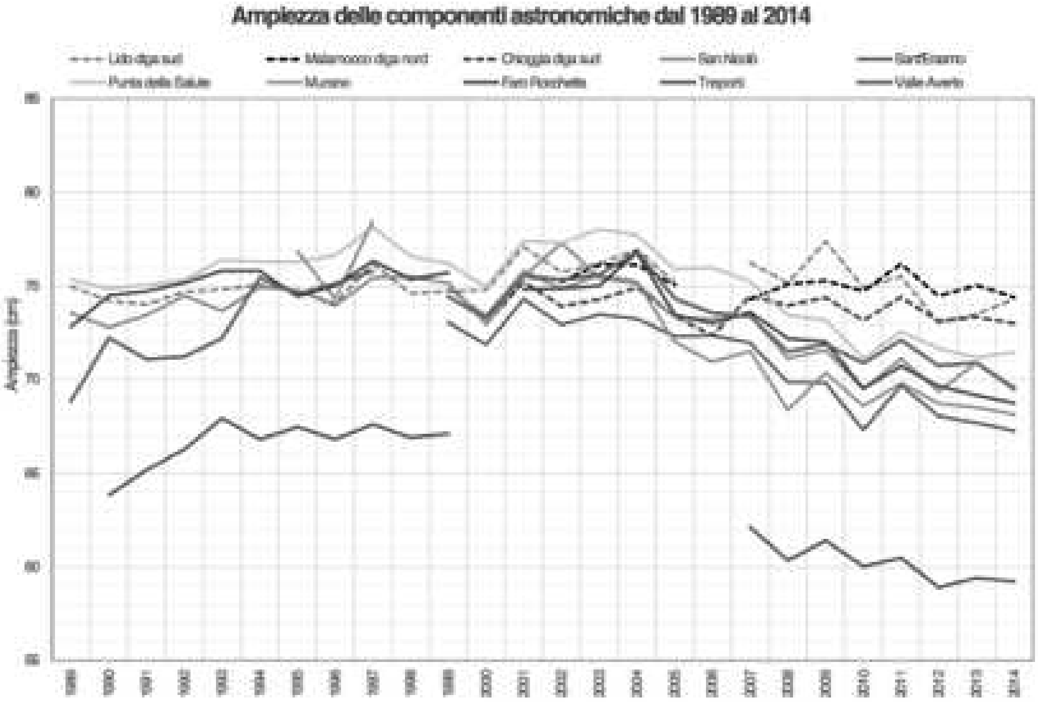

Fig. 5 – Amplitude of the astronomic tide for the stations shown. Data was obtained by adding together the amplitudes of the 7 principal components of the astronomic tide (source: data processing by ISPRA).

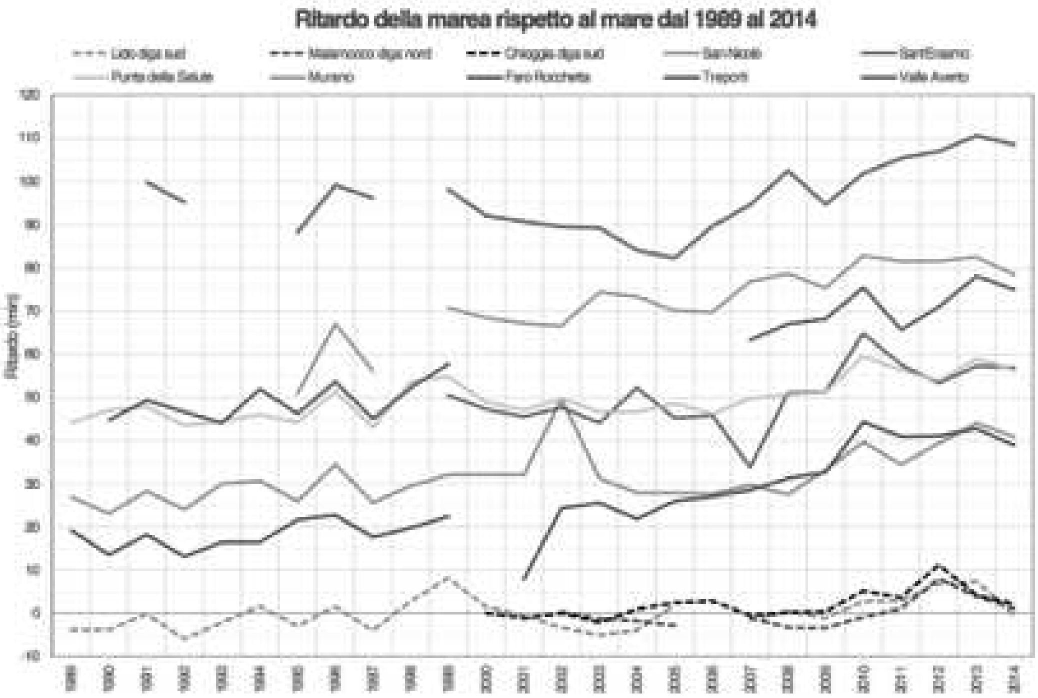

Fig. 6 Time delay (minutes) of the astronomic tide for the measurement stations listed, relative to sea-level. Data was obtained by calculating the average of of the phases of each component, weighted according to the amplitude of the specific component (source: data processing by ISPRA).