ACCADEMIA NAZIONALE DEI LINCEI

ATTI DEI CONVEGNI LINCEI
320

XXXIV Giornata dell'ambiente

STRATEGIE DI ADATTAMENTO AL CAMBIAMENTO CLIMATICO

(Roma, 8 novembre 2016)

ROMA 2018
BARDI EDIZIONI
EDITORE COMMERCIALE

Si ringrazia la «Associazione Amici dell'Accademia dei Lincei»
per la collaborazione offerta alla edizione del presente volume

ISSN: 0391-805X
ISBN: 978-88-218-1167-8

FINITO DI STAMPARE NEL MESE DI LUGLIO 2018

Antica Tipografia dal *1876* srl – 00186 Roma, C.so del Rinascimento, 24
Azienda con Sistema Qualità certificato ISO 9001-14001 - OHSAS 18001

Tide propagation within Venice Lagoon: recent evolution trends

Marco Cordella, Franco Crosato, Maurizio Ferla[1], Devis Canesso, Bruno Matticchio[2], Antonio Rusconi[3]

Study area

Venice Lagoon lays in the North Western sandy shores of Adriatic Sea. It represents the largest Mediterranean lagoon with its area of 550 km². The surrounding coastline presents a large amount (~2400km²) of areas below the mean sea level, consisting mainly of reclaimed land, which have experienced significant subsidence effects in the last century. Venice Lagoon is therefore increasingly exposed to the risk of flooding from both storm surge and sea level rise.

The Lagoon has undergone many transformation processes over the past centuries, consisting in defences lines built to escape either from the risk of landfilling by rivers discharges within the Lagoon (the rivers diversion) or from flooding by the sea (the so called "Murazzi"). The morphological evolutions in the past centuries have been analysed in detail (D'Alpaos, 2003 and 2010). Tide follows a counterclockwise path along the Northern Adriatic Sea (Polli, 1961) and enters Venice Lagoon through three inlets: Lido, Malamocco and Chioggia. During good weather conditions, the Lagoon can be virtually divided into three independent basins, each fed by a single inlet (Goldmann, 1975). Watershed lines can be identified as basin boundaries influenced by concurrent fluxes from two different inlets. These boundaries can somehow modify over the tidal time scale, given specific meteorological forcings. Anyhow, long term modifications are related to morphological changes occurred mainly during the XX century. It is well known that construction of breakwaters at the three inlets and dredging of artificial channels for commercial and industrial purposes caused changes of the tidal characteristics within the lagoon (Dorigo, 1961, Magistrato alle Acque, 1934 e 1939, Ministero dei lavori pubblici, 1970, Rusconi, 1987). Detailed analysis has been carried out on tide characteristics and changes within the Venice Lagoon in the first half of the XXth century and the beginning of the XXIth (Polli, 1952, Ferla, 2007).

Since 2003 the mobile barriers system (Mo.S.E.) has been currently in construction at the three inlets to prevent the city of Venice and its lagoon from storm surge flooding. The mobile barriers system has been included in the framework of the Flood Risk Management Plain (FRMP) of the North Eastern Alps District approved on March, 2016 by the Italian Ministry for Environment according to the EU Directive 2007/60. The Mo.S.E. barriers are also considered as a protection measure against sea level rise in the city of Venice and its lagoon as a consequence of climate change. In the last 20 years, indeed, Venice flooding frequencies increased and Northern Adriatic tide gauges registered a steep sea level rise (ISPRA, 2015). Nevertheless it should be noticed that the works for the construction of the mobile barriers have changed the configuration of the three inlets narrowing and reducing the cross sections of the three main channels. On the basis of the recorded sea level, this paper outlines the observed variations on tidal amplitude and delay from the open sea to the inner part of the lagoon as a possible consequence of the inlet's changed configuration.

Given the importance of tidal dynamics for all aspects related to both ecosystem health and human activities, a widespread tide gauges network exists and long-term recordings are available. Tide gauges data from Venice Lagoon network (RMLV[4]), managed by ISPRA, are periodically submitted to quality checks and validation processes to ensure the best quality of information. Such procedures include astronomical tide evaluation over time and harmonic constants time series comparison (ISPRA, 2012).

[1] ISPRA – Servizio Laguna di Venezia, Castello 4665 Venezia
[2] Ipros Ingegneria Ambientale, Corso del Popolo, 8 35131 Padova
[3] Università IUAV, Santa Croce 191 30135 Venezia

Astronomical tide

In order to determine the astronomical tide, Fourier analysis is commonly used. Through this analytical approach, a complex continuous function, such as the tidal fluctuation, can be decomposed into a sum of periodic functions, sine and cosine, that can be treated more easily one by one, and are somehow related to each astronomical forcing. The so-calculated tide is hence centred on the origin of the reference system and, in order to obtain the real tide, the mean sea level H_0 and the non-astronomical components (e.g. storm surge, seiches, etc.) need to be added.

The astronomical tide amplitude at time *t* in any tide gauge station can therefore be expressed by a relationship of type: $H_t = H_0 + \Sigma A_i*\cos(\omega_i t-\varphi_i)$, where A_i is the tide amplitude in centimetres, ω_i is the angular velocity in degrees/hour, φ_i is the phase delay in degrees, while *t* indicates time in hours. Each of the functions $A_i*\cos(\omega_i t-\varphi_i)$ is called astronomical tide component, while the parameters A_i and φ_i represent the harmonic constants to be calculated starting from the tide gauge data. The angular velocity ω_i, obtained from the astronomical component period, is not dependent by the location of the tide gauge station (Shureman, 1971). In the Northern Adriatic sea, seven of such curves are enough to determine with acceptable approximation the astronomical tide amplitude. The components are named with abbreviations, related to their astronomical origin: 4 occur on semi-diurnal timescale (M2, S2, N2, K2), and the other ones (K1, O1, P1) on a diurnal timescale (Polli, 1960). The harmonic constants of each component can be conveniently calculated using the least squares method on long enough time series of sea level data. Once the harmonic constants have been found, the astronomical tide range for each station can be easily calculated and the propagation delay, as compared with an arbitrary point/instant, can be determined.

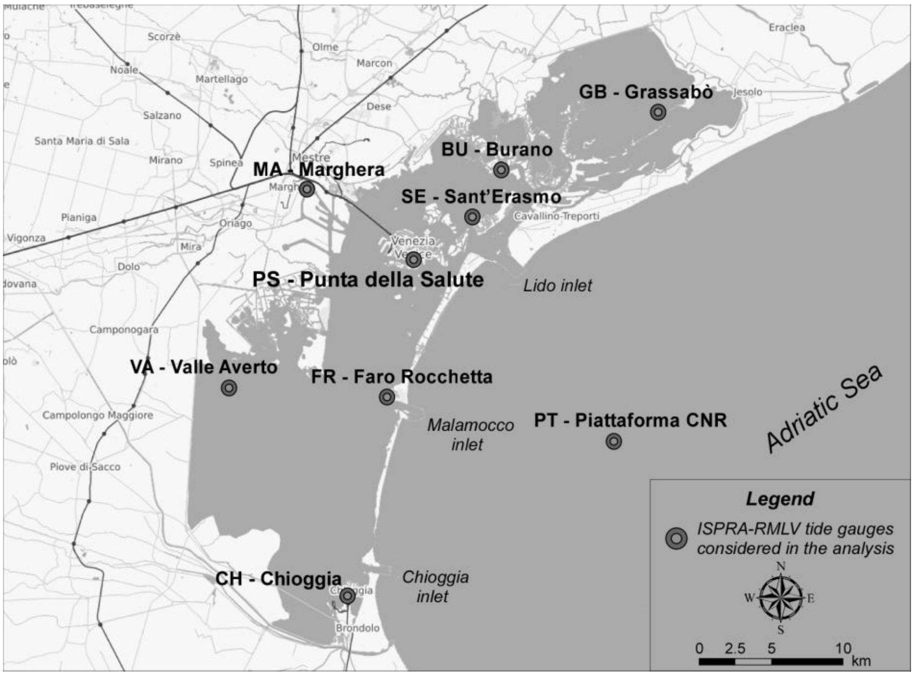

Figure 1 – ISPRA - RMLV selected tide gauges

Results

To ensure a proper coverage of the whole Venice Lagoon, 8 tide gauge stations have been selected for the aim of the present analysis. Piattaforma Acqua Alta, located 8 nautical miles off the venetian coastlines, has also been considered as reference station, being not influenced by any changes occurred inside the Lagoon (Fig.1). Pre-analysis tests were carried out in order to assess the reliability of Piattaforma Acqua Alta[4] (PT) dataset, which confirmed the stability of amplitude and phase of such tide time series. PT signal has hence been considered as a reference datum, to make tidal variation within the Venice Lagoon fully understandable. As regards tide amplitudes within the lagoon, they appear to be substantially stable until the years 2003/2004, which is the period when works at the three inlets started. Instead, in the following years, all stations registered a notable fall of tide amplitude. The response of the Venice Lagoon appears not to be homogeneous: Northern Lagoon stations show a minor decrease in amplitude in comparison with Central and Southern Lagoon. In the extreme Northeast wing of the lagoon, the tidal amplitude decreased by 5% (stations of BU - Burano, GR - Grassabò). As a matter of fact, stations in central lagoon show a steeper drop in amplitude by 7/8%, particularly the ones located in the tidal watershed fed by Malamocco inlet (FR - Faro Rocchetta - and VA - Valle Averto, fig. 2). Observed changes involve not only tidal amplitude but also phase delays with respect to the sea. On average, tidal wave takes 20 minutes more to reach the same tide gauge at the end of the observing period than before 2003/2004, whilst for some stations in Central Lagoon delay increases of about 30 minutes (FR - Faro Rocchetta and VA - Valle Averto, fig. 3).

Such modifications suggest that the lagoon hydrodynamics have changed significantly in the last years. It may be presumed that the limits of the areas subject to the influence of each sea inlet (watershed) have moved. In particular, Lido inlet may have expanded its area of influence while the watershed related to Malamocco inlet could have decreased. This would imply changes in tidal currents paths, resulting in a reinforcement of the currents in areas close to Lido inlet with respect to the central part of the lagoon. Such changes can probably explain the increase of tidal current speed that is observed in some of the canals of Venice city, since canals flows are related to the instantaneous phase shifts of the tide between the Grand Canal and the lagoon. This phenomenon, evident to anyone sailing in the canals, is not adequately monitored and is likely to be underestimated, not only for the consequences on the canals navigation, but especially for the possible damages to the ancient buildings in direct contact with water. Finally, a different hydrodynamic regime related to tide propagation changes would also imply direct consequences in residence time and water quality, not to mention the effects on suspended solid transport with possible impacts on the Venice Lagoon sediment budget. The results here presented are consistent with the findings of other works (Ferrarin, 2015).

Being such results evident from the data of all stations within the Lagoon but the offshore station (PT), the logical conclusion is that, whatever caused such strong variations on tidal regime, it is to be searched within the Lagoon itself. In addition, even if local actions inside the Lagoon could be considered, it is unlikely that they are eligible for justifying such whole lagoon patterns of tide behaviour. Instead, such changes are very likely to be related with the modifications occurred at the three inlets for the construction of the movable gates system.

[4] Piattaforma Acqua Alta data are gently supplied by ICPSM – Istituzione Centro Previsioni e Segnalazioni Maree – Comune di Venezia (www.comune.venezia.it/maree)

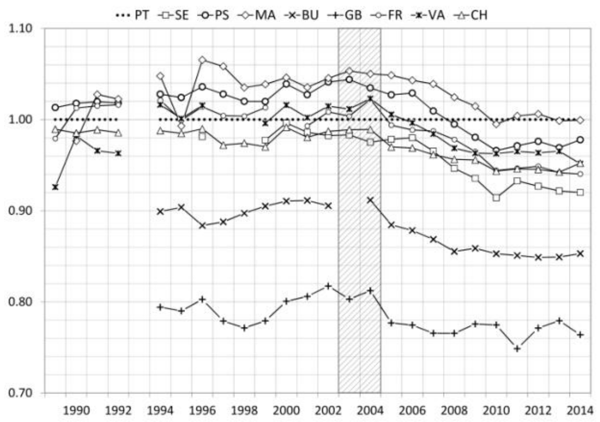

Fig. 2 – Amplitude reduction index within Venice Lagoon in comparison with Northern Adriatic Sea. The vertical bar highlights the beginning of amplitudes changes.

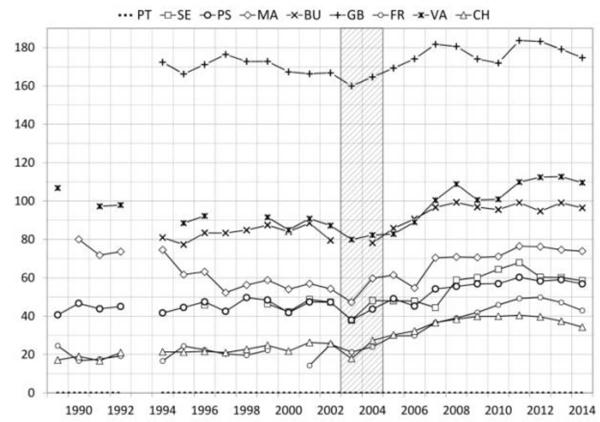

Fig. 3 – Tidal delays in Venice Lagoon (minutes). The vertical bar highlights the beginning of delays changes.

References

D'Alpaos L. (2003) "Conoscere il comportamento idrodinamico della laguna del passato per progettare la laguna del futuro", Atti dell'Istituto Veneto di LL. SS. AA. Tomo CLXII (2003-2004), Classe di Scienze Fisiche, Matematiche e Naturali.

D'Alpaos L. (2010) "L'evoluzione morfologica della Laguna di Venezia attraverso la lettura di alcune mappe storiche e delle sue carte idrografiche", Comune di Venezia – Istituzione Centro Previsioni e Segnalazioni Maree, Legge Speciale per Venezia.

Dorigo L. (1961) "Le correnti di marea nei porti e nella Laguna di Venezia", Istituto Veneto di Lettere Scienze e Arti, Commissione di studio dei provvedimenti per la conservazione e difesa della laguna e della città di Venezia, Rapporti preliminari, pp. 127-147.

Ferla M., Cordella M., Michielli L., Rusconi A. "Long-term variations on sea level and tidal regime in the lagoon of Venice", Estuarine, Coastal and Shelf Science 75 (2007) 214-222.

Ferrarin C., Tomasin A., Bajo M., Petrizzo A., Umgiesser G., "Tidal changes in a heavily modified coastal wetland", Continental Shelf Reasearch 101 (2015) 22-33.

Goldmann A., Rabagliati R., Sguazzero P. (1975) "Characteristic of the tidal wave in the Lagoon of Venice", Venice Scientific Center, Technical Report n.47.

ISPRA (2012) "Manuale di mareografia e linee guida per i processi di validazione dei dati mareografici, Manuali e Linee Guida 77/2012.

ISPRA (2015) "Annuario dei dati ambientali 2014-15", Capitolo Idrosfera pp.146-163

Magistrato alle Acque di Venezia - Ufficio Idrografico (1934), "Carta della Laguna di Venezia", pubblicazione n. 134, Roma, Istituto Poligrafico dello Stato.

Magistrato alle Acque di Venezia - Ufficio Idrografico (1939), "Superfici che compongono la Laguna", pubblicazione n. 134 bis, Istituto Poligrafico dello Stato.

Ministero dei Lavori Pubblici (1970), "L'influenza di variazioni recenti di superficie e profondità su la marea lagunare di Venezia", Ministero dei Lavori Pubblici, Comitato per lo studio dei provvedimenti a difesa della città di Venezia ed a salvaguardia dei suoi caratteri ambientali e monumentali, Roma, Istituto tipografico dello Stato.

Polli S. (1952) "Propagazione della marea nella Laguna di Venezia" Annali di Geofisica, vol. V, n°2, pp. 273-292.

Polli, S (1960) "La propagazione delle maree nell'Adriatico" Atti del IX convegno dell'Assoc. Geofisica Italiana. Roma, 20-21 nov. 1959.

Polli S. (1961) "La propagazione della marea nel golfo di Venezia". Rapporti preliminari della commissione di studio per la conservazione della Laguna e della città di Venezia. Vol. 1 – Istituto Veneto di Lettere Scienze e Arti, Venezia.

Schureman, P. (1971) "Manual of harmonic analysis and prediction of tides" Washington, D.C. : U.S. Govt. Print. Off. : U.S. Coast and Geodetic Survey