Interactive comment on "Assessing hydrological effects of human interventions on coastal systems: numerical applications to the Venice Lagoon"

by C. Ferrarin, M. Ghezzo, G. Umgiesser, D. Tagliapietra, E. Camatti, L. Zaggia, and A. Sarretta.

Hydrol. Earth Syst. Sci. Discuss., 9, 13839-13878, 2012

Response to Anonymous Referee #1

Q(General Comments)
This paper focuses on numerical simulations of both Local and Overall Water Renewal Times for past, present, and future conditions of the Venice Lagoon. The major contributer to changes in Water Renewal Time is the construction and the frequency of closure of the mobile barriers (MoSE) at the lagoon inlets, which depends on the past, present, and anticipated future sea levels. The MoSE is the major human intervention to the Venice Lagoon. The authors addressed the effect of the MoSE properly and quantitatively for years 2002, 2012, and during the anticipated future sea level rise.

Two more numerical applications for years 1927 and 1970 addressed the period before the construction of the MoSE in a very qualitative manner. Interventions that were very briefly mentioned included the destruction and restoration of salt marshes and the dredging of the ship channel. The paper is very specific to the Venice Lagoon and it is very specific to the effect of its protective barrier, MoSE, on Water Renewal Time.

R(General comments): We would like to thank the reviewer for all the constructive comments. This study describes the effects of past, present and future human intervention on the hydrodynamics of the Venice Lagoon. We disagree when the referee when he states that the application for years 1927 and 1970 were carried out in a qualitative manner. Model results indicated that the 1970 to 2012 changes in morphology had a smaller impact on the lagoon's hydrodynamic with respect to the cases of predicted closure of mobile barriers and sea level rise. All considered scenarios (including 1927 and 1970) are properly simulated and for each of them the water renewal time are quantified.

The model applications of 1927, 1970 and 2002 show that past interventions have slightly changed the hydrodynamic regime. The model simulations of SLR and MoSE scenarios show what will be the impact on the Venice Lagoon in the future. The methodology is by no means limited to Venice but can be applied to any coastal environment where management plays a major role in shaping natural environments such as lagoons or the coastal zone. Moreover, the discussion of the modelling results in the context of the classification of lagoons and the hydro-ecological considerations place this study in a more general debate of coastal lagoon evolution and response to the climate change.

Q(Specific Comments):

Q(1). The title should be more relevant to the content. Except for the construction and operation of the MoSE, human interventions (i.e., page 13844) in the Venice Lagoon were not quantitatively analyzed in this paper. A more relevant title can be "Effects of Protective Barriers and Seal Level Rise on Water Renewal in Venice Lagoon."

R(1): We prefer to keep the original title since, to our opinion, the manuscript properly describes the response of the lagoon to the past, present and future morphological evolution. See response to general comments.

Q(2). The reference datum for measuring vertical changes (water surface, sea level rise, MoSE, bed elevation) has to be clearly stated in the paper. Any "local datum" has to be related to the reference datum.

R(2): We specified in the text the reference datum for the sea level. See also reply to question 6.

Q(3). Four numerical model grids with different coastline and bathymetry were generated to cover the four simulation periods for 1927, 1970, 2002, and 20012. It should be mentioned if the calibration (page 13850) was performed for all these grids and what were the calibration parameters for both hydrodynamics and transport.

R(3): We specified in the manuscript that the model applications for the scenarios 1970, 2002 and 2012 were validated in precedent studies, while the model application for the 1927 scenario could not be validated due to lack of measurements. The calibration parameters could be found in the cited publications.

Q(4). Baseline simulations should be included for the effect of Sealevel Rise on Water Renewal Time without any closures of the MoSE. These simulations will show the actual degree of choking these barriers are causing to the Lagoon.

R(4): We carried out the mentioned simulations. The results of these simulations are presented in Figure 7 and discussed in the manuscript in the following paragraph: "In order to investigate the degree of choking the MoSE barriers are causing to the Lagoon we carried out three additional simulations which consider SLR without any closure of the inlets during high tide events. Basin-wide average water renewal times of these simulations are 8.4, 8.8 and 9.2 days for a SLR of 10, 20 and 30 cm respectively. Increase in the WRT is only due in this case to the increase in the lagoon volume which is not fully compensated by the increase water fluxes through the inlets. As shown in Figure 7, where results of these simulations are presented as gray stars, closing the MoSE barriers will have a stronger effect on water renewal in comparison with only SLR".

Q(5). The 4-page long Section 4.2 "Hydroecological implications" includes general information. This section should include only the implications that relate to the presented analysis of Vince Lagoon. After some cleaning, only the last 4 paragraphs may be kept in this section.

R(5): It is true that section 4.2. includes many general information, but some of them, to our opinion, are necessary to introduce the discussion. Anyway, following reviewer suggestion we shortened this section and focus more on the implication related to the presented analysis.

Q(6). Figure 2: what is the datum for the shown bathymetry? Is it the same "local datum" mentioned in the text? If not, define the relation between the two.

R(6): We specify in the caption of figures 2 and 5 that bathymetry and elevation are referred to the IGM42 datum. Moreover, we state at the end of the "Study area" section that the sea-level reference datum is about 27-28 cm higher than the IGM42 datum used for the bathymetries (Sarretta et al, 2010). The vertical datum difference was accounted in the simulations.

Q(7). Figures 4 and 6 are very hard to read at the presented scale. Each of these figures includes 4 maps of the spatial distribution of Water Renewal Time. It takes the reader considerable effort to compare between them and verify the explanation in the relevant text. a. All these figures should be converted to the spatial distribution of the difference (or %) in change between a reference scenario (for example 2002) and the other studied scenarios (i.e., (WRT-WRT2002), or

(100(WRT-WRT2002)/ WRT2002)); respectively). Such spatial distributions will directly point the reader to areas of change and the magnitude and trend of change (+ or -) relevant to each scenario. b. Figure 4 (A) shows year 1930. It should be consistent with the text indicating the year 1927.*

R(7): We modified Figures 4 and 6 according to the reviewer comment showing the spatial distribution of the difference between scenarios (in days). Figure 4 presents now the Water Renewal Time distribution for year 1927 (Figure 4A), the difference in WRT between 1970 and 1927 (Figure 4B), the difference in WRT between 2002 and 1970 (Figure 4C) and the difference in WRT between 2012 and 2002 (Figure 4D). Figures 4B-D now well correlate with Figure 5 enhancing the clarity of the discussion. Figure 6 presents now the WRT distribution for the scenario with no SLR and closure of the inlets (Figure 6A), the difference in WRT between scenarios SLR_10 and SLR_00 (Figure 6B), the difference in WRT between scenarios SLR_30 and SLR_00 (Figure 6C) and the difference in WRT between scenarios SLR_50 and SLR_00 (Figure 6D).

Q(8). Figure 5 and the relevant text (page 13852): a. The two figures should be separated into two independent figures because their horizontal axes are different. b. Otherwise, they should be identified as (A) Water renewal time, and (B) Bathymetry. The caption should mention these figures. c. For consistency, the word "bathymetry" should be changed to "elevation" in the caption. d. The legend for Figure (B) should not have the data for 2002. The caption for figure (B) should alert the reader that the 2002 data does not exist. e. The authors should identify the reference datum (zero elevation) for the measurements in both figures. f. To validate any quantitative comparison between the two graphs, the vertical axes should have the same scale and units [e.g., Area (km2), or Area (%)].

R(8): Figure 5 was partially modified according to reviewer suggestions: (a, b) The two figures have been identified as (A) Water renewal time and (B) Elevation, and the caption mentions these figures; (c) the word bathymetry in the caption has been changed to elevation; (d) 2012 label has been deleted from Figure 5B and the caption now mentions that there is no bathymetry dataset for 2012; (e) The two figures are both referred to the free floodable surface of the Venice lagoon. The vertical axes of the figure 5B is now expressed as Area (%) and the datum of elevation has been specified in answer R(2) and R(6); (f) The water residence time is referred the whole area of the Venice lagoon, but it is calculated on the volume of the water column as specified in the methodology section. The relation between elevation and water renewal time is mediated from the effect of the changes in the spatial distribution of the morphologies on the water circulation (as showed in the figure reporting the difference between water renewal time in different years.). We are not calculating a balance between areas, but illustrating the cause-effect relationship between WRT and elevation. This figure is now discussed together with Figure 4.

Q(9). Figure 7: The horizontal axis should be changed to reflect the time from 1927 into the future. The expected times for SLR of 10, 30, and 50 cm can be estimated from relevant literature or models. A legend similar to that in Figure 8 should be added to figure 7.

R(9): We modified Figure 7 according the suggestions of the reviewer changing the horizontal axis to time from 1920 to 2100 and adding the legend. Moreover we included the following sentence in the manuscript (Section 2.3.: Simulation set-up): "The expected times for SLR of 10, 30 and 50 cm can be estimated to be 2030, 2060 and 2090, considering that recent observations find sea level tracking at the upper range of IPCC projections (Allison et al., 2009, Umgiesser et al., 2012)".

Q(10). Figure 8: a. The sketches showing leaky, restricted, and choked waterbody are very qualitative and they are not relevant to Venice Lagoon. The main cause of the restriction to the lagoon is the frequent operation of the MoSE. These sketches should be removed. b. Introducing the "flushing time," which is a different time scale, is confusing. Should the vertical axis represent average water renewal time or flushing time? In addition, the curve showing flushing time does not add anything new to the analysis and it should be removed from the figure together with the relevant text (page 13855, paragraph 3). c. With the above adjustments to the figure, the eight data points should plot on a relevant vertical axis with a maximum similar to that in Figure (7) to delineate the trend with FVE, which should be similar to that in Figure 7 but reversed.

R(10): We agree with the reviewer that these sketches (from Kjerfve and Magill(1989)) are qualitative, but they are commonly used to describe different types of lagoons. With this figure, which includes the leaky, restricted and choked water body sketches, we want to broaden this study on the more general context of the classification and characterisation of lagoons. For this purpose, Figure 8 now reports also the numerical results, obtained by applying the same model SHYFEM, of other five Mediterranean lagoons: the Marano-Grado Lagoon in the Northern Adriatic Sea, the Taranto basin in the Ionian Sea, the Cabras Lagoon in Sardinia, the Mar Menor in Spain and the Nador Lagoon in Morocco. These environments range from a leaky type to a choked type of basins and give a representative picture of the coastal lagoons situated around the Mediterranean Sea. Details of model application to these lagoons can be found in the cited references.

We agree with the reviewer that the flushing time in this figure is confusing and therefore we removed it and not discussed in the manuscript.

Q(Technical corrections)

1. *Abstract, sentence before last: change "increased" to "increase".*
2. *Section 1.1, Study area, 4th bullet, 2nd sentence: change "inlets" to "inlet".*
3. *Section 2, Material and methods, 2nd sentence: change "estimated computing" to "estimated by computing".*
4. *Page 13846, Equations: a. The three equations need to be numbered (1), (2), and (3) b. Renumber equations in the following pages accordingly. c. Equation (3): use different counter than l (e.g., L) under the summation (P) to represent number of all layers. d. Equation or explanation to define shear stress ,τ ,must be added.*
5. *Page 13850: paragraph before last, sentence before last: change "total flux on the three inlets" to "total flux in the three inlets".*
6. *Page13851, 1927-2012 evolution, 2nd paragraph: remove text in the 2 sentences between "The variation of the relative. . .. .almost unchanged."*
7. *Page 13855, paragraph 3: remove the text starting from "The inverse of FVE. . .. . ." to the end of this paragraph.*
8. *Section 4.2, Hydroecological implications: remove the text as explained in No. 5 in the Specific Comments.*

R(Technical corrections): Corrected according to reviewer's comment.

The new figures modified according to suggestions of reviewer #1 are reported below.

Christian Ferrarin (on behalf of all authors)

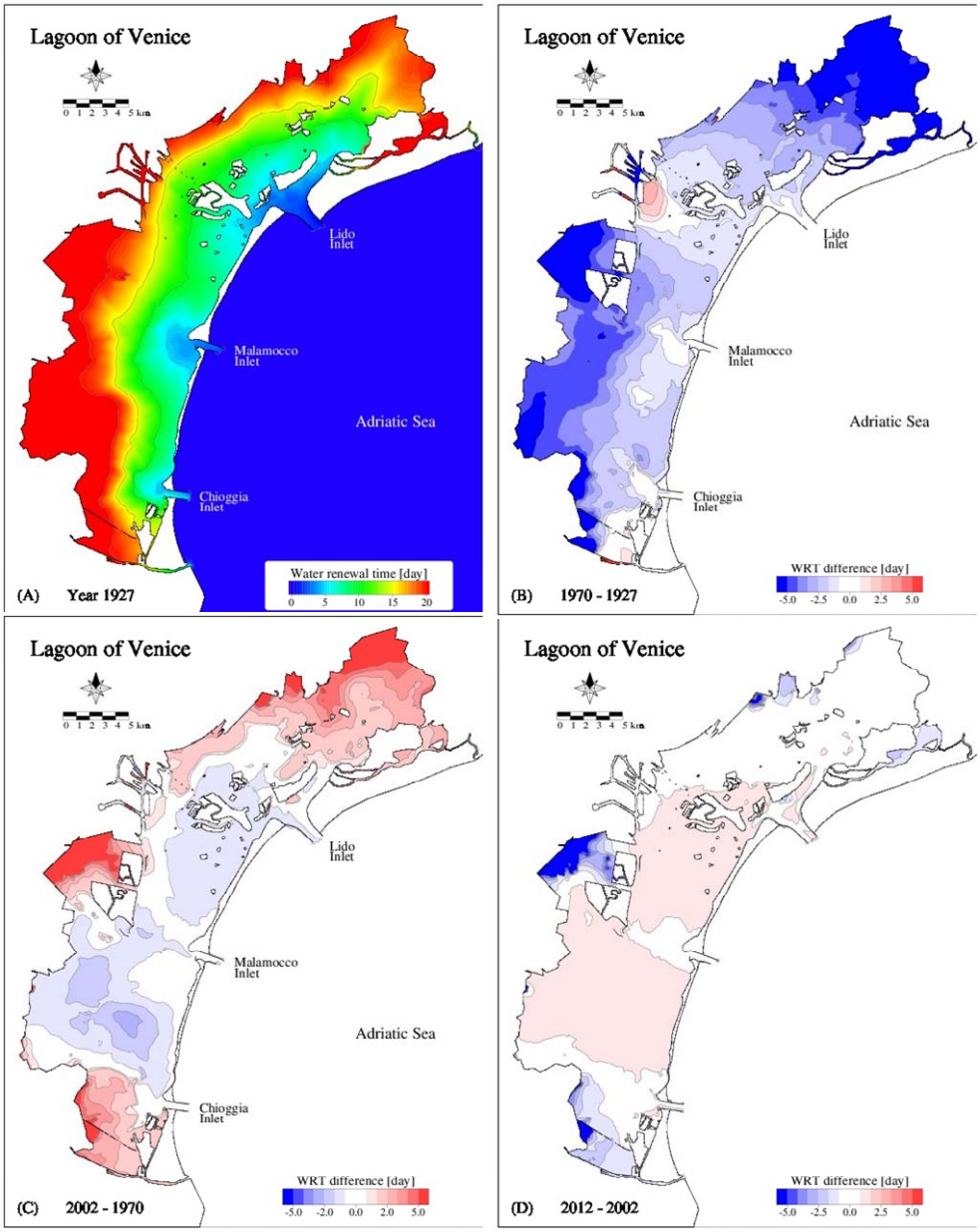

Fig. 4: Map of water renewal time computed by the model for the 1927 (A) and maps of the WRT difference (in days) between 1970 and 1927 (B), between 2002 and 1970 (C) and between 2012 and 2002 (D). WRT values were computed as average of four replicas obtained by forcing the model with water level and wind observations of year 2002.

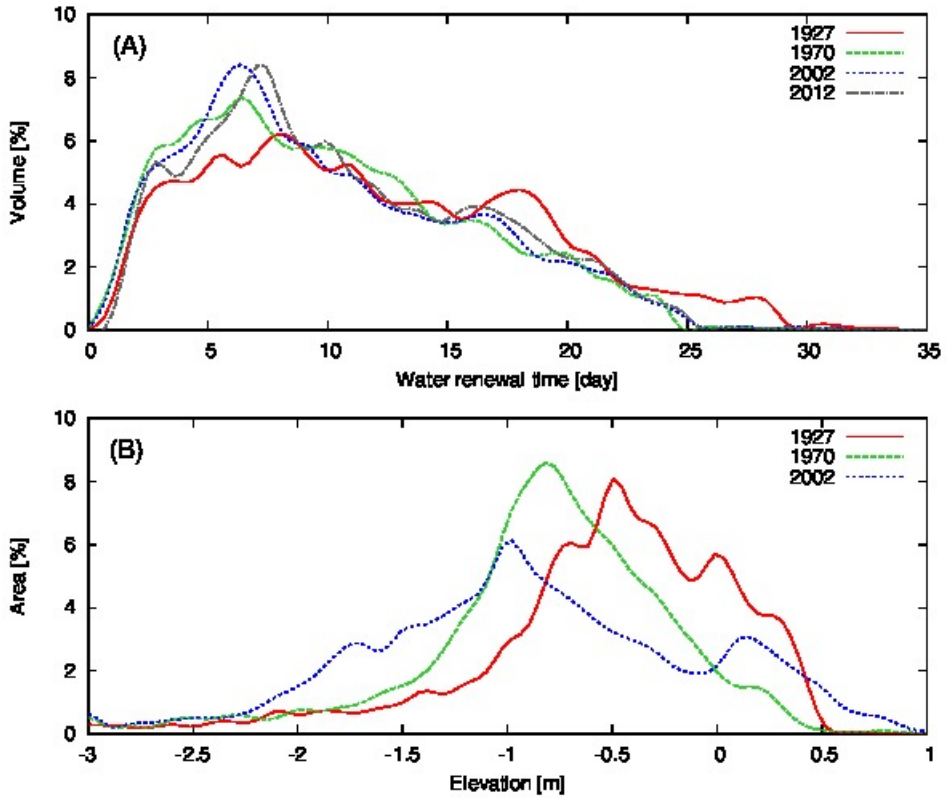

Fig. 5. Frequency distribution of water renewal time, by % of volume (A), and elevation, by % of area (B), for the 1927 (red continuous line), 1970 (green dashed line), 2002 (blue dotted line) and 2012 (gray dot-dashed line) scenarios. There is no available elevation dataset for the 2012 scenario and therefore the elevation over the lagoon was assumed to be unchanged from year 2002.

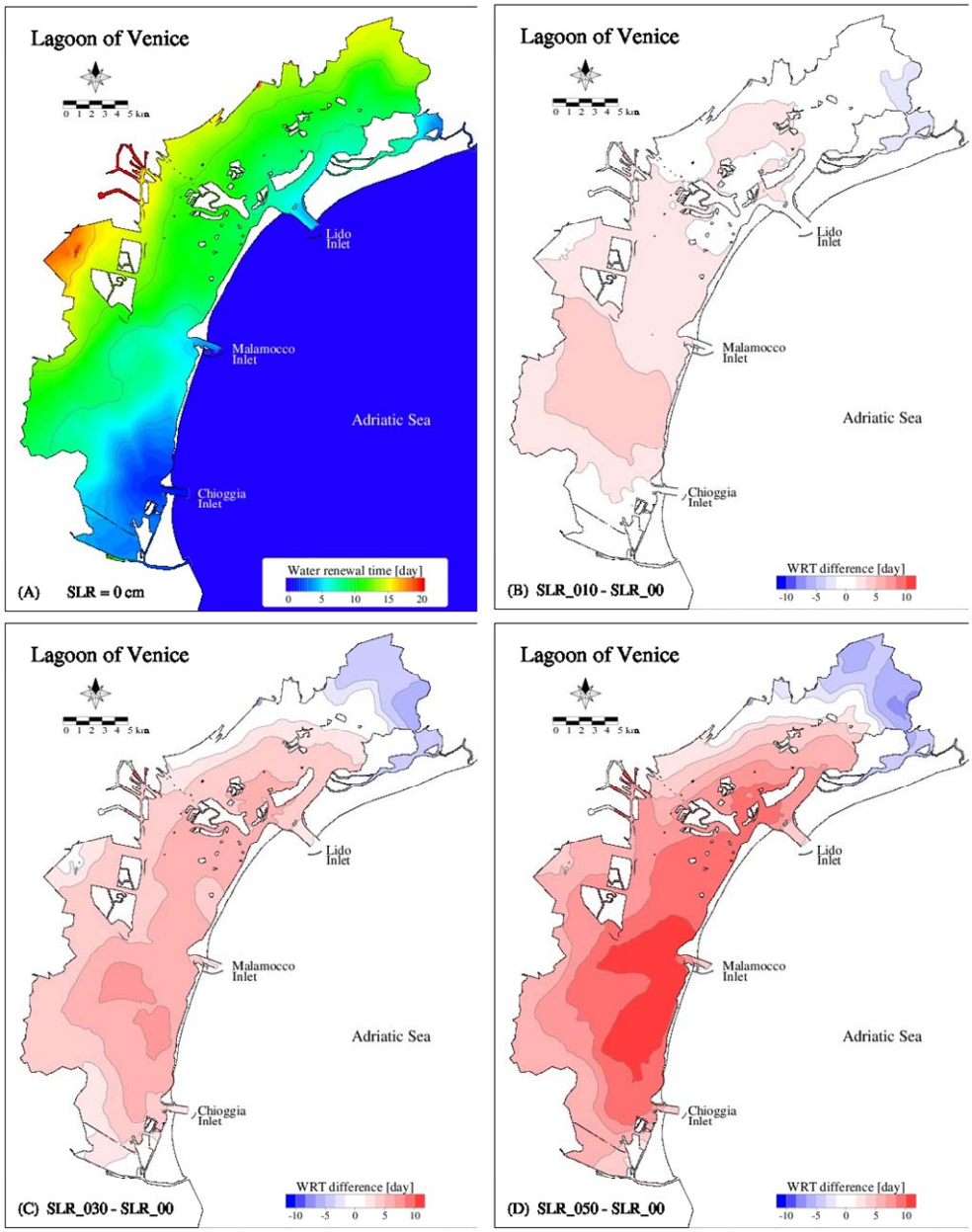

Fig. 6: Map of water renewal time computed by the model for the SLR-00 scenario considering the closure of the inlets during high water events (A), and maps of WRT difference (in days) between SLR-10 and SLR-00 scenarios (B), between SLR-30 and SLR-00 scenarios (C) and between SLR-50 and SLR-00 scenarios (D). The period of reference is November 2002.

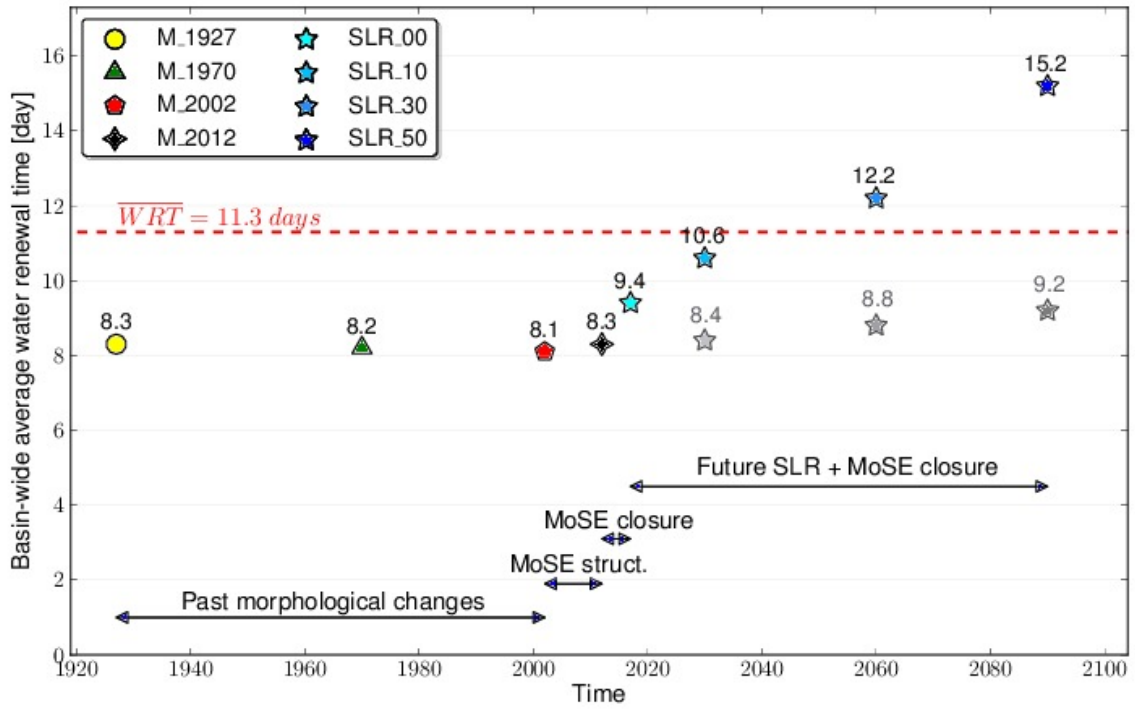

Fig. 7. Evolution of average water renewal time in the Venice Lagoon under fall-winter conditions considering: past morphological changes, the MoSE structures, the closure of MoSE barriers during high tide events and future sea level rise of 10, 30 and 50 cm. Gray stars indicate the results of SLR simulations without considering closure of the mobile barriers at the inlets. The red dashed line at WRT=11.3 days indicates the average yearly value of the present situation (2012, simulation Y 2012).

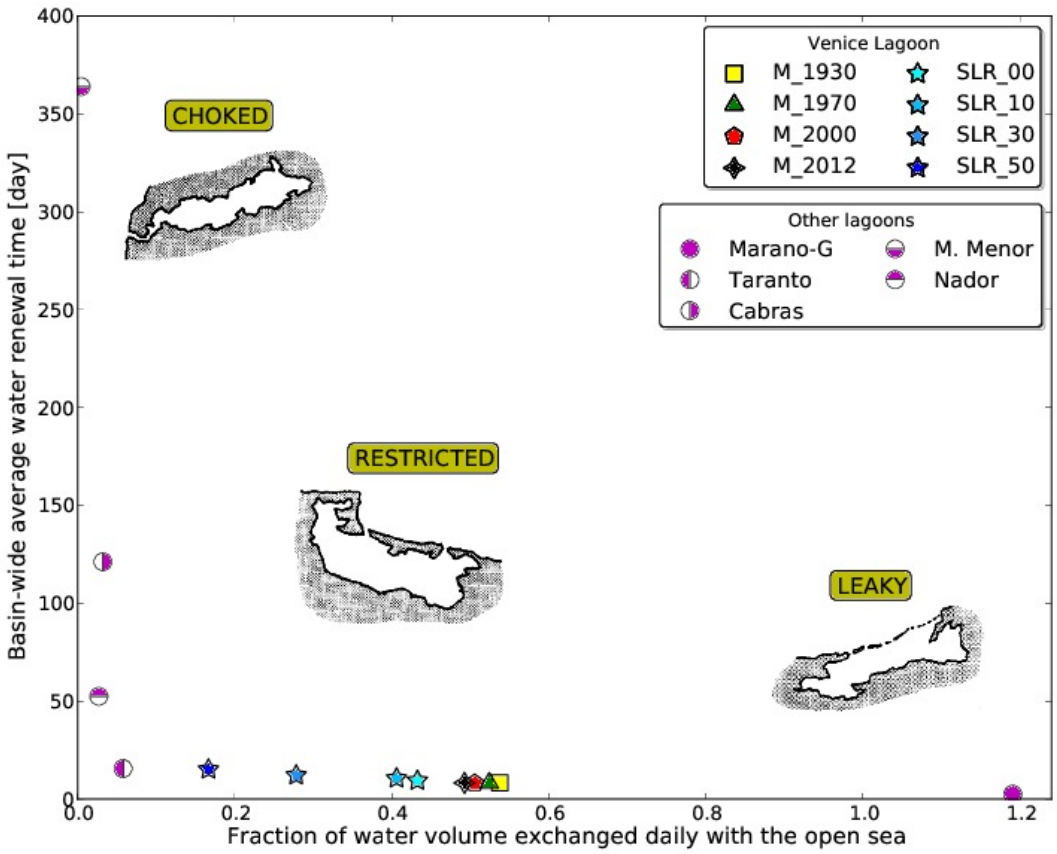

Fig. 8. Evolution of lagoon type, based on water exchange between lagoon and ocean and WRT, in the different scenarios under fall-winter conditions. Leaky, restricted and choked water body sketches are from Kjerfve and Magill (1989). Numerical results of other five Mediterranean lagoons are marked with filled and half-filled magenta circles.