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Modeling the Venice Lagoon residence time

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Abstract

In this work the water residence time of the Venice Lagoon has been computed using a 2D hydrodynamic model. The model is based on the finite element method. It solves the shallow water equations on a spatial domain that represents the whole Adriatic Sea and the Venice Lagoon.

The residence time has been defined through the remnant function of a passive tracer released inside the lagoon. The renewal capacity of the Venice Lagoon has been investigated when forced by the astronomic tide and by the two main local winds, bora and scirocco.

The importance of the return flow from the Adriatic into the lagoon is shown. This influence has been quantified by the definition of the return flow factor that has been computed for each scenario.

Keywords: Residence time; Finite elements; Hydrodynamic models; Venice Lagoon

1. Introduction

Lagoons, lakes and semi-enclosed basins are commonly subject to intensive anthropogenic inputs that modify both the trophic state and the health of the whole ecosystem. The intrinsic cleaning capacity of these environments can be represented by two different types of processes: biogeochemical processes and physical processes. The first concerns all the mechanisms that reduce the active pollutant concentration by modifying its reactivity both by biological and chemical neutralization. The latter includes those processes that neutralize the pollutant effect simply by mechanical removal from the ecological compartment (Rodhe, 1992).

Sedimentation, evaporation advection and diffusion can be reasonably considered the main physical processes that influence the cleaning capacity of a lagoon ecosystem water compartment. Through the advection and diffusion mechanisms, the water mass is transported to the open sea where it is mixed with the sea

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water. The time spent by each water particle inside the lagoon gives an idea of the efficiency of this physical cleaning process. The determination of the water residence time is thus of major interest in the environmental management of the lagoon basins (Baleo et al., 2001).

If the tide is the main forcing for the water circulation, such as in the Venice Lagoon case, the cleaning capacity of the basin is influenced by the characteristic of the tidal exchange. In this situation, the flushing mechanism is produced through repeated exchange of the intertidal water volume between the embayment (the Venice Lagoon) and the receiving water body (the Adriatic Sea). Water entering the embayment on flood tide fills the intertidal volume until high water is reached. This new water mixes with the existing water in the embayment and, as the tide falls, the intertidal volume of water discharges out of the embayment on the ebb tide. Some fraction of the discharged water is lost by exchange and mixing within the receiving water body the remainder returns to the embayment on the subsequent flow. Not all the water entering on the incoming tide is then ‘new water’. Therefore, the tidal flushing and the cleaning capacity depend not only on the tidal range and the basin geometry but also on the effluent water that returns on the subsequent flood tide, the so called return flow, as defined by Sanford et al. (1992). Hence, in order to investigate the cleaning capacity of the Venice Lagoon that can be characterized through the water residence time, the influence of the return flow on the basin flushing dynamic has to be taken into account.

In this work the renewal capacity of the Venice Lagoon (Fig. 1) has been investigated with a 2D hydrodynamic model, already implemented in the Venice Lagoon (Umgiesser and Bergamasco, 1995; Umgiesser, 2000; Umgiesser et al., 2004; Cucco and Umgiesser, 2005; Solidoro et al., 2004). Using the finite element method, the model solves the circulation pattern of both the lagoon basin and the Adriatic Sea induced by different meteomarine forcings. Wind and tidal forcing have been prescribed in the model to obtain three different idealized scenarios. For each simulation a passive tracer subject to transport and diffusion processes has been released inside the lagoon. Solving the decay of the tracer concentration for the whole area, the residence time is computed. It represents a time scale for the renewal capacity of the fluid volume. The results for the various scenarios have then been compared with each other. The importance of the various forcings on the renewal capacity of the basin has been investigated. Finally, the influence of the return flow on the lagoon residence times has been quantified by means of a numerical experiment.

The residence time is a fundamental concept to estimate the transport time scale for both geochemical and biological processes occurring in a lagoon basin. Its relevance has been assessed by many authors. For example, the growth dynamics of a patch of phytoplankton in a tidal flow is a strong function of the total amount of time spent in a particular environment (Monsen et al., 2002). Furthermore, the distribution of the residence times shows the importance of transport processes in shaping the spatial patterns of temperature, specific conductivity, *Chl a* and dissolved oxygen in a lagoon basin (Monsen et al., 2002). Even if the importance of such a parameter for the environmental management of the Venice Lagoon is clear, no references or estimates are available in the literature. Therefore, this can be considered as a first scientific investigation in which the Venice Lagoon residence time is computed and discussed.

2. Methods

In this section the hydrodynamic model used in the simulations is described and the definition of the residence time and the return flow factor is given.

2.1. Hydrodynamic model

A 2D hydrodynamic model of the Venice Lagoon and the Adriatic Sea, based on the finite element method, has been used (Umgiesser and Bergamasco, 1993, 1995; Umgiesser et al., 2004; Cucco and Umgiesser, 2005). The model has been applied and calibrated (Umgiesser et al., 2004) to reproduce the tidal and wind induced water circulation in the Venice Lagoon and in the northern Adriatic Sea.

The numerical computation has been carried out on a spatial domain that represents the two basins through a finite element grid. The grid contains 10,948 nodes and 20,013 triangular elements (Fig. 1).

The model considers as open boundary the strait of Otranto, elsewhere as closed boundaries the whole