A system for the sustainable management of Lithuanian marine resources using novel surveillance, modeling tools and an ecosystem approach"

Hydrodynamic modeling for the coastal zone: applications of the SHYFEM model

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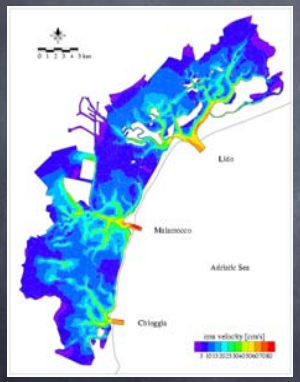
Introduction

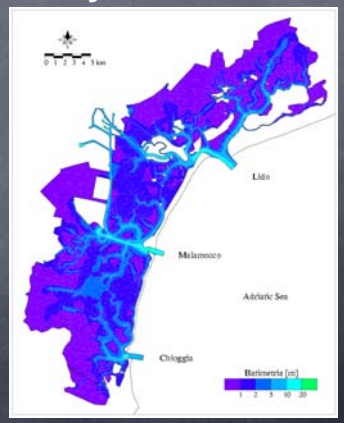
- Measurements are expensive – but we can supplement them with modeling results
- Ecological models might not be ready for forecasting the ecosystem evolution, but they certainly are for hindcast simulations
- Numerical models can interpolate in time and space missing measurements, once the model is calibrated
- Modeling is a powerful tool for coastal zone management and sustainable development

Hydrodynamic model: SHYFEM



- finite elements
- primitive equations
- semi-implicit time stepping scheme
- z or sigma coordinates in the vertical
- description of tidal marshes

Hydrodynamic model: grid and bathymetry



Hydrodynamic Equations

THE NUMERICAL MODEL

- **Shallow Water Finite Element Model (SHYFEM)**

$$\frac{\partial U}{\partial t} - fV + gH\frac{\partial \zeta}{\partial x} + RU + F_x = 0$$

$$\frac{\partial V}{\partial t} + fU + gH\frac{\partial \zeta}{\partial y} + RV + F_y = 0$$

$$\frac{\partial \zeta}{\partial t} + \frac{\partial U}{\partial t} + \frac{\partial V}{\partial t} = 0$$

$$U = \int_{-h}^{\zeta} u\,\partial z \qquad V = \int_{-h}^{\zeta} v\,\partial z$$

Barotropic transport

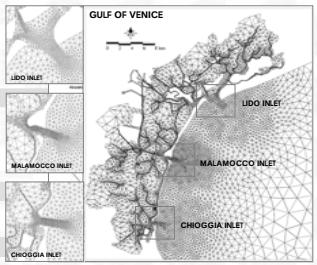
$$R = \frac{c_b}{H}\sqrt{u^2 + v^2}$$

Friction term

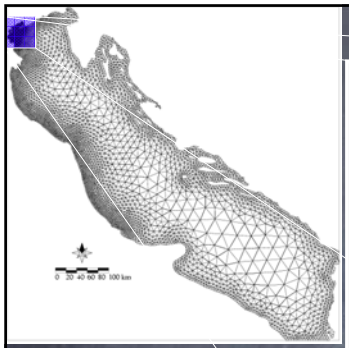
$$F_x = \int_{-h}^{\zeta}\left[\frac{\partial p_a}{\rho_0 \partial x} + \hat{f}_x\right]dz + \frac{1}{\rho_0}\left(\tau_x^a - \tau_x^w\right)$$

$$p_a = p_0 + \int_{z}^{\zeta} g\rho^0(z)\,dz$$

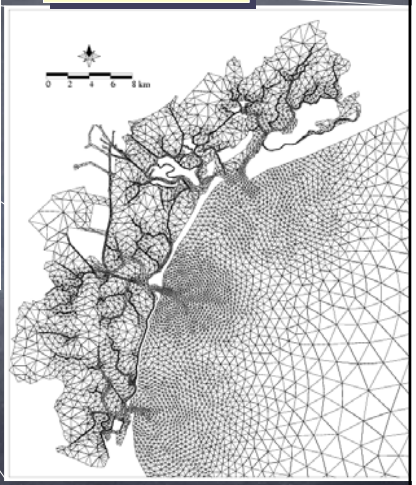
Wind stress, non-linear advective terms ...



MODEL DOMAIN F.E. grid of the Adriatic Sea and Venice Lagoon (8072 nodes, 15269 elements, spatial resolution varying from 30 Km to 30 m)

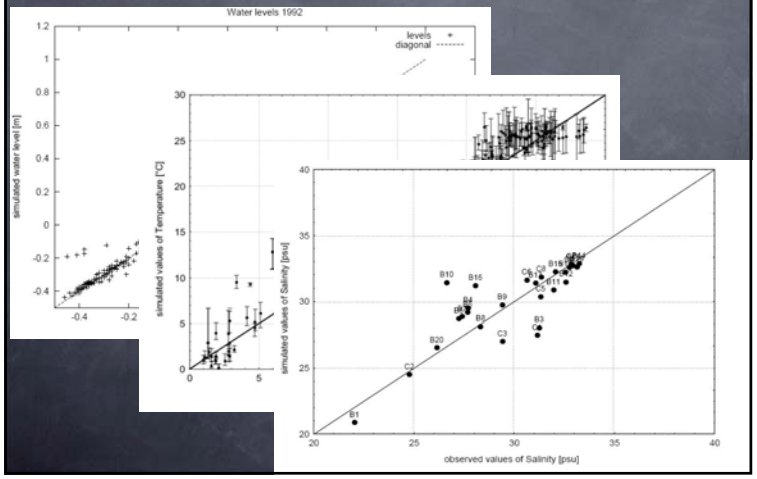


High resolution area

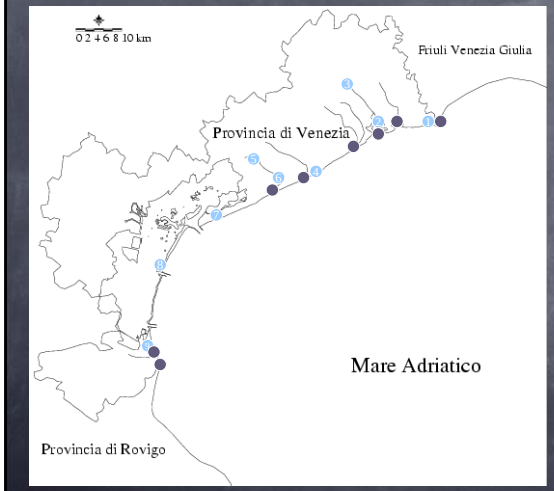


Finite element grid of the Adriatic Sea – Venice Lagoon

Validation of SHYFEM



Map of the province

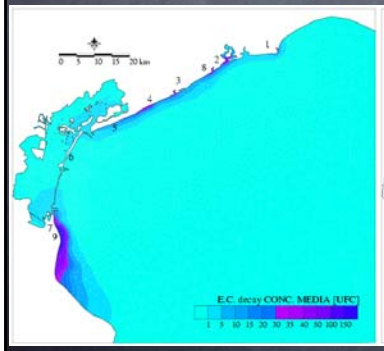


● = treatment plants

○ = rivers

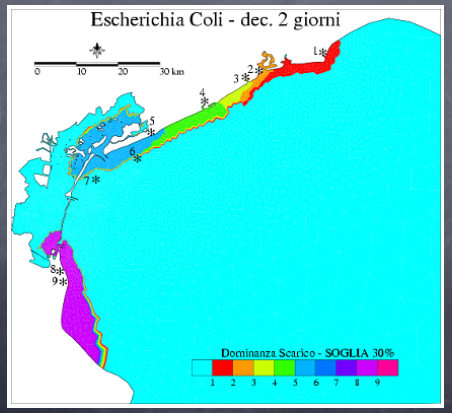
Results for Escherichia Coli

Average concentration



Exceeding the threshold (in days/year)

Influence of treatment plant pollution on the coastal zone



Residence time: definition

•Cucco, A. & Umgiesser, G., 2004. Modeling the Venice Lagoon Residence Time. (Accepted in "Ecological Modeling").

RESIDENCE TIME (Eulerian approach)

" THE TIME REQUIRED FOR EACH ELEMENT OF THE DOMAIN TO REPLACE THE MASS OF A CONSERVATIVE TRACER, ORIGINALLY RELEASED, WITH NEW WATER "

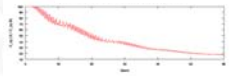
•TRACER [C] IN THE LAGOON = 100 %

$$S_0 = S(t=0)$$

•TIDE AND WIND ACTION DRIVES IT OUT THE BASIN

$$\frac{\partial S}{\partial t} + \frac{\partial uS}{\partial x} + \frac{\partial vS}{\partial y} = K_H\left(\frac{\partial^2 S}{\partial x^2} + \frac{\partial^2 S}{\partial y^2}\right)$$

•TIME DECAY OF THE TRACER CONCENTRATION



THE TRANSPORT TIME SCALES

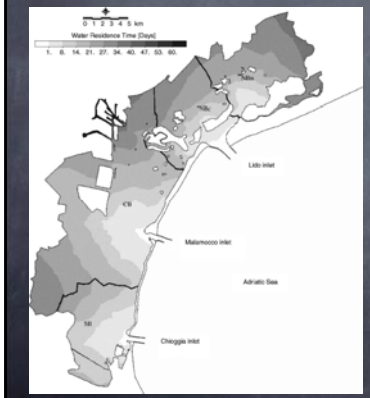
•DEFINITION OF THE REMNANT FUNCTION (Takeoka, 1984 a,b)

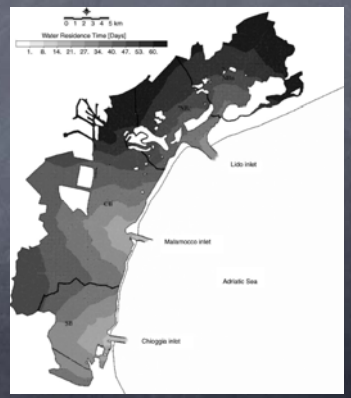
$$r(x,y,t) = S(x,y,t)/S_0$$

•DEFINITION OF THE WATER RESIDENCE TIME

$$\tau(x,y) = \int_0 r(x,y,t)\,dt$$

Residence time: results





Applications in Europe

Roskilde Fjord, Denmark

Orbetello Lagoon

Cabras Lagoon

Mar Menor, Spain

Nador Lagoon, Morocco

Mellieha Bay, Malta

Curonian Lagoon, Lithuania

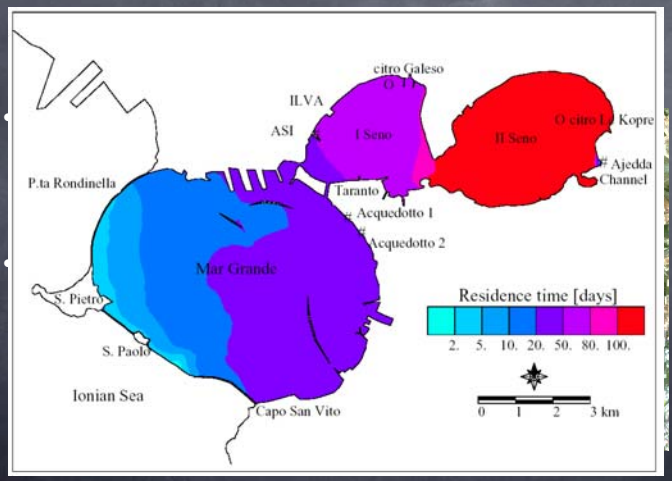
Venice Lagoon

Danube Delta

Sea of Taranto

Taranto

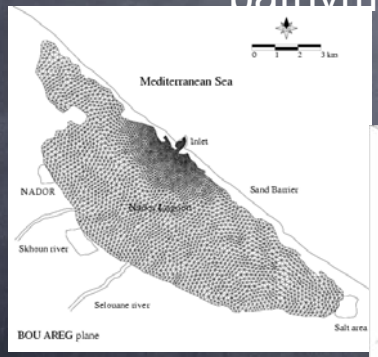
- Circulation modeling
- Use of remote sensing with modeling techniques
- Estimation of fresh water fluxes through salinity modeling



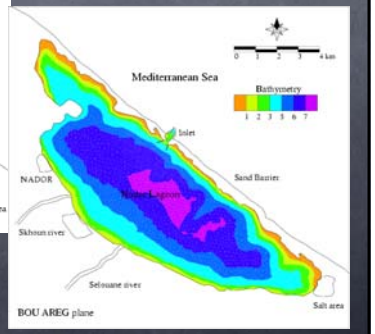
Area characteristics

- Surface 115 km^2
- Shallow water (max depth 8m)
- Single passage with the open sea
- Aquaculture activity
- Wastewater and sewage discharge

Nador lagoon: grid and bathymetry



Tool: finite element model (SHYFEM)

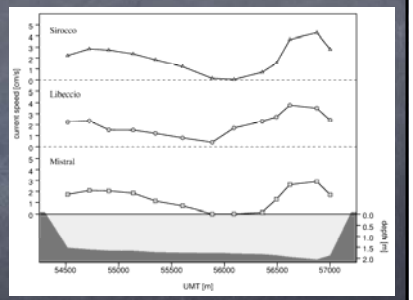


3464 nodes and 6486 elements

Sea water intrusion

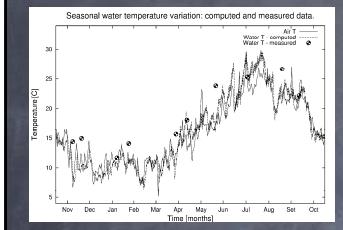
- The model can be used to simulate various scenarios of how the sea water mixes with the lagoon waters
  - under WSW winds
  - under ENE winds
- Salinity and temperature distribution can be modeled (inter annual variation)

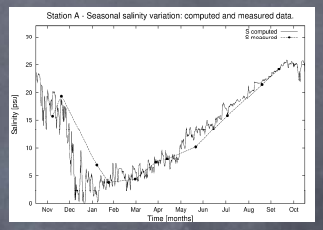
The Cabras Lagoon, Italy

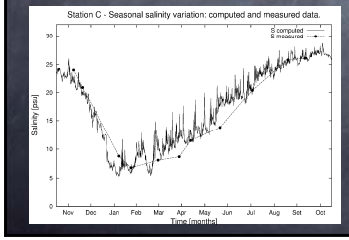


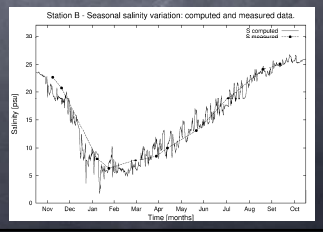
Residual Currents

Temperature and salinity

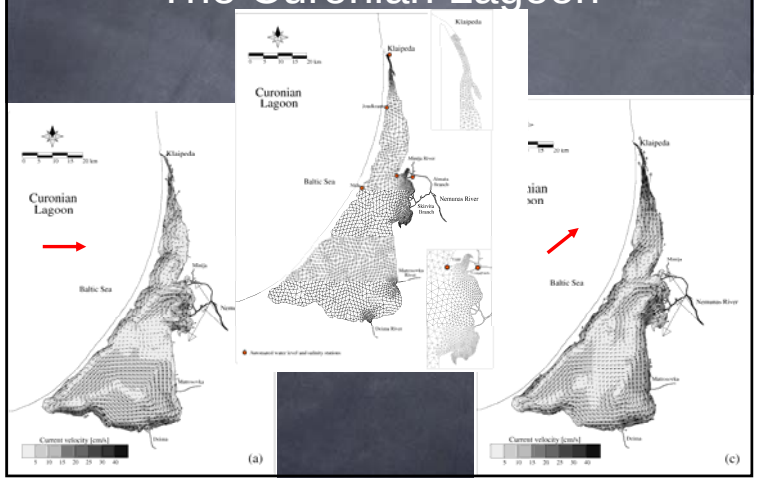




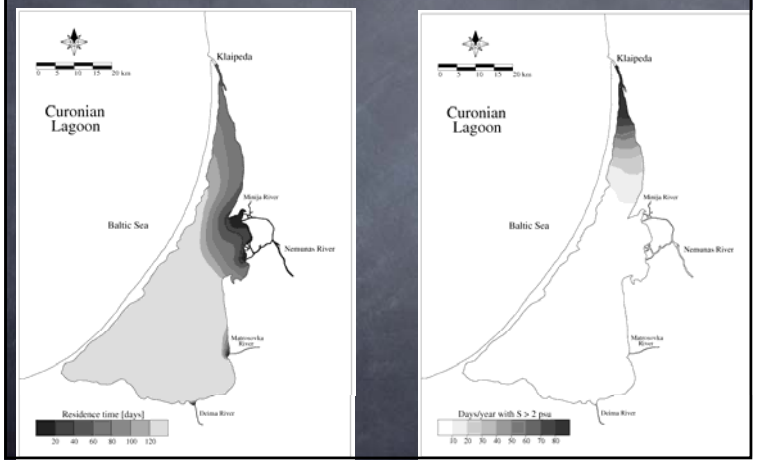




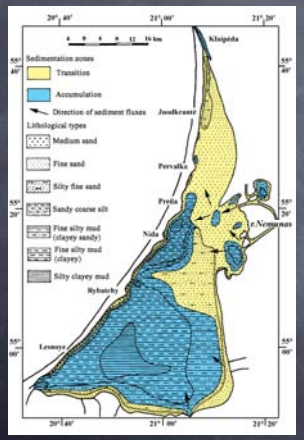
The Curonian Lagoon

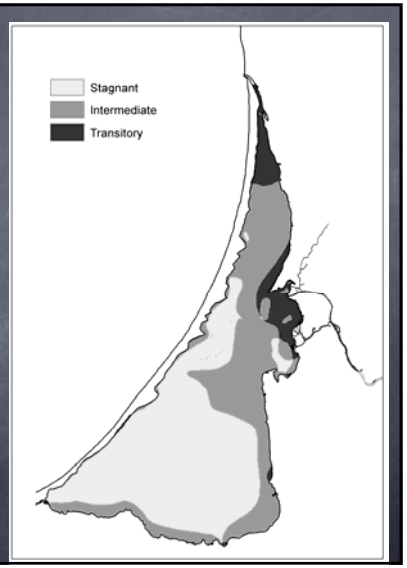


Residence time and salinity



Zonation





From Gulbinskas, 1995

Sediment Transport Modeling

FEM
Hydrodynamic Model

SWAN
Wave Model

Current variables and others
current speed
current direction
water depth
suspended sediment concentration

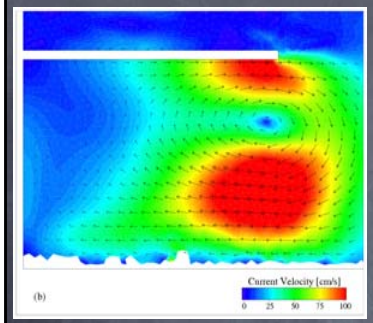
INTEGRATED MODEL

Wave variables
significant wave height
wave period
wave direction

Bed and sediment variables
bed structure
sediment transport rates

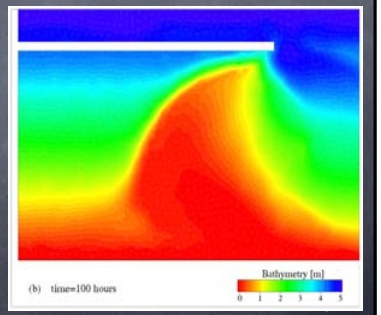
SEDTRANS96
Sediment Transport Model

Sediment characteristics
grain size
critical shear stress
density
settling velocity

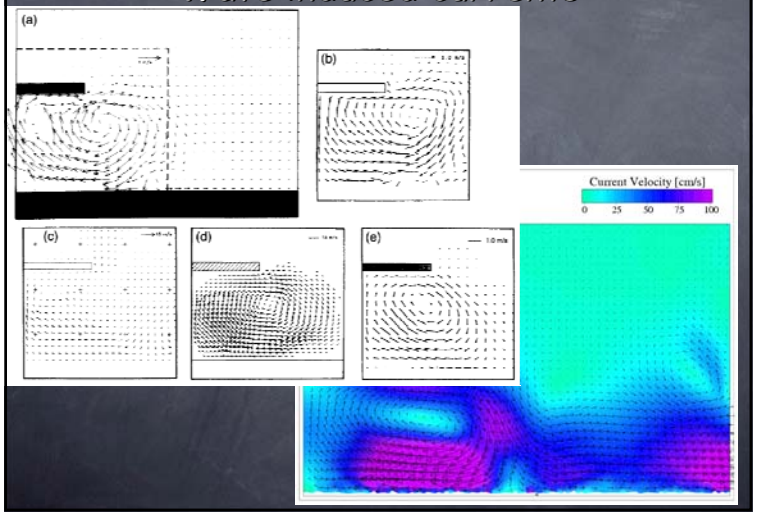


Wave induced currents

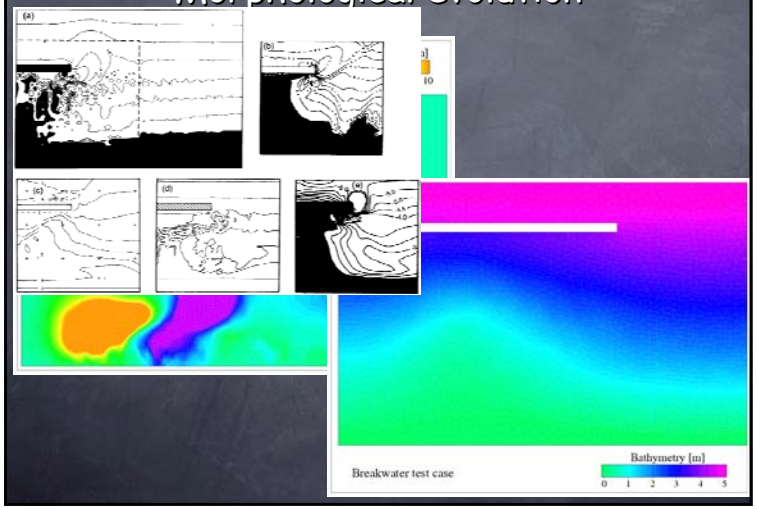
Morphological evolution



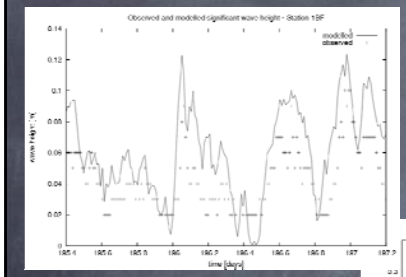
Wave induced currents

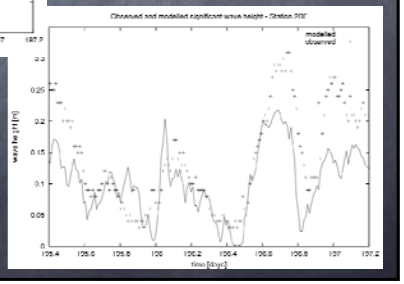


Morphological evolution

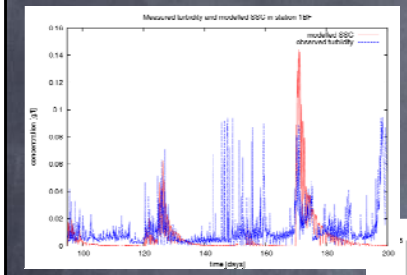


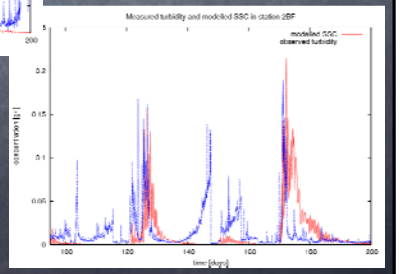
Validation – Wave model



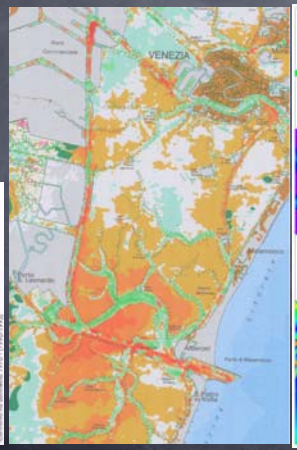


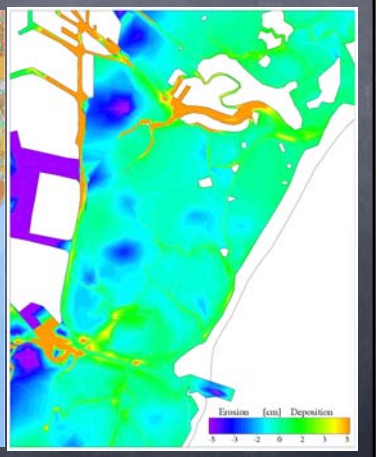
Validation -Turbidity & SSC





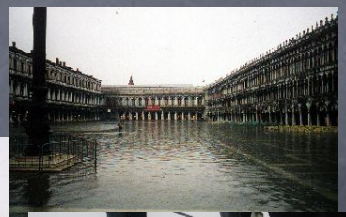
Long term morphological evolution

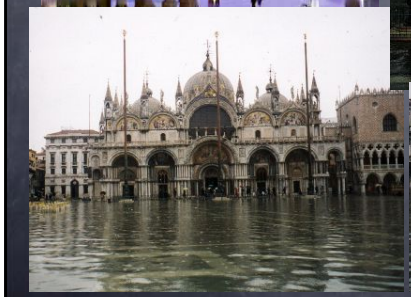




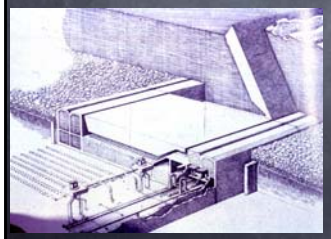
Flooding of Venice

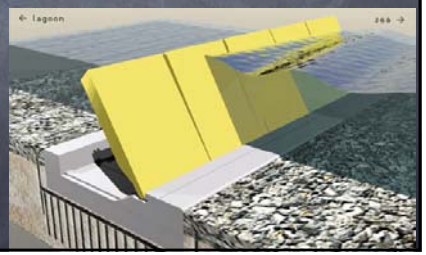
Venice is flooded 20 times a year





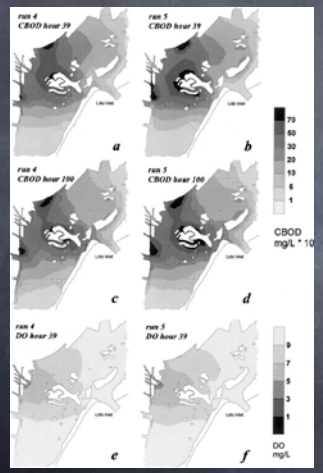
Mose: how it works

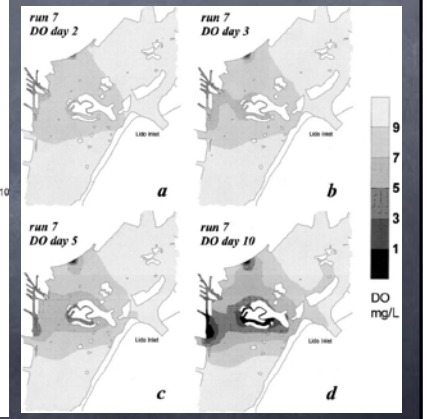




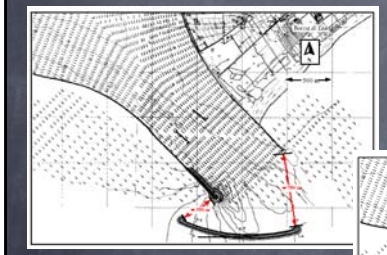
The prototype

DO with closed lagoon barriers





Detailed modeling of the Lido inlet

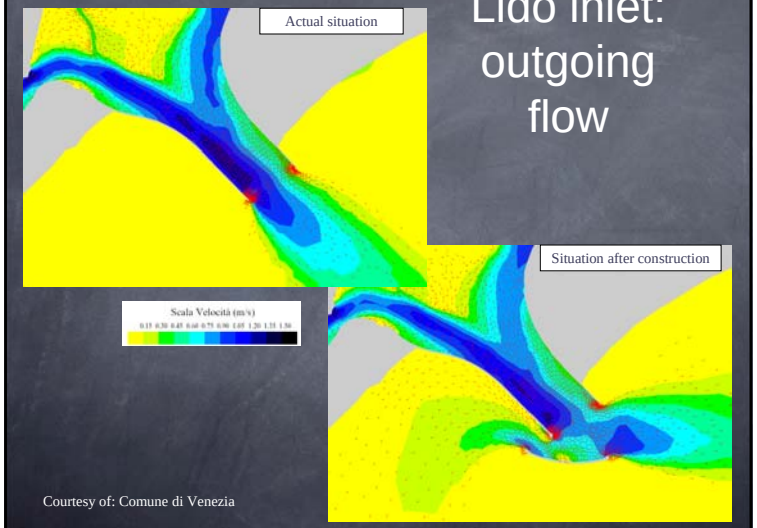


proposed interventions by CVN in 2002

proposed interventions by Venice Municipality in 1999

Courtesy of: Comune di Venezia

Lido inlet: outgoing flow



Courtesy of: Comune di Venezia

Impact of waste water discharge

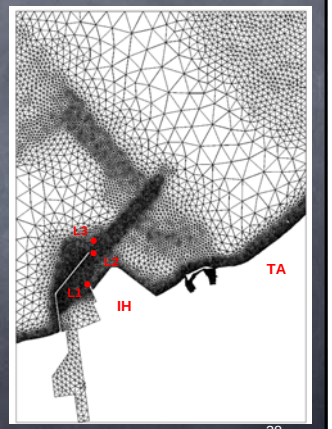
- Plan sewage outfall in the sea
- Assess impact of the sewage outfall to the surrounding areas

Test area:

- Industrial port [IH]
- Possible sewage outlet position [L1, L2, L3]
- Touristic area [TA]

Test case:

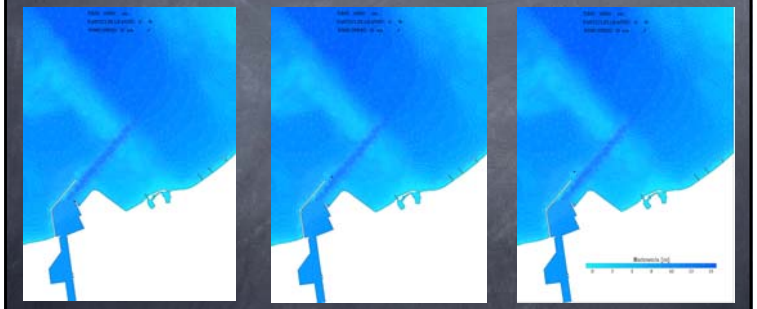
- Different scenarios (tide, wind,…)
- Different sewage outlet positions [L1 L2 L3]
- Evaluation of the impact



Evaluate impact of pollutants

- SW wind with speed of 8 m/s

L1 L2 L3



Conclusions

- Modeling tools are a valuable tools for assessing environmental problems in the coastal zone
- The Venice Lagoon is a prototype of lagoon where all possible processes can be studied ranging from hydrodynamic to ecological applications
- Modeling approach is needed for coastal zone management and sustainable development
- The models are available in the public domain for the application to other areas (see `http:/www.ve.ismar.cnr.it/shyfem`)