LATEST
MODELLING TECHNIQUES
FOR SHALLOW SEAS

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Accademia dei Georgofili
Logge degli Uffizi Corti - Firenze

A multi-scale strategy towards numerical simulation of coastal erosion

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Università di Pisa

DICI
Dipartimento di Ingegneria Civile e Industriale

Motivation and objectives

It has been developed a strategy towards the numerical simulation of coastal erosion based on a **multi-scale approach.**

This strategy is based on the coupling between:

- the open-source software **Delft3D**, which is used to simulate **flow and wave dynamics on large areas**
- the in-house developed code **ShallowBox**, used for more **detailed simulations in a smaller area of interest**.

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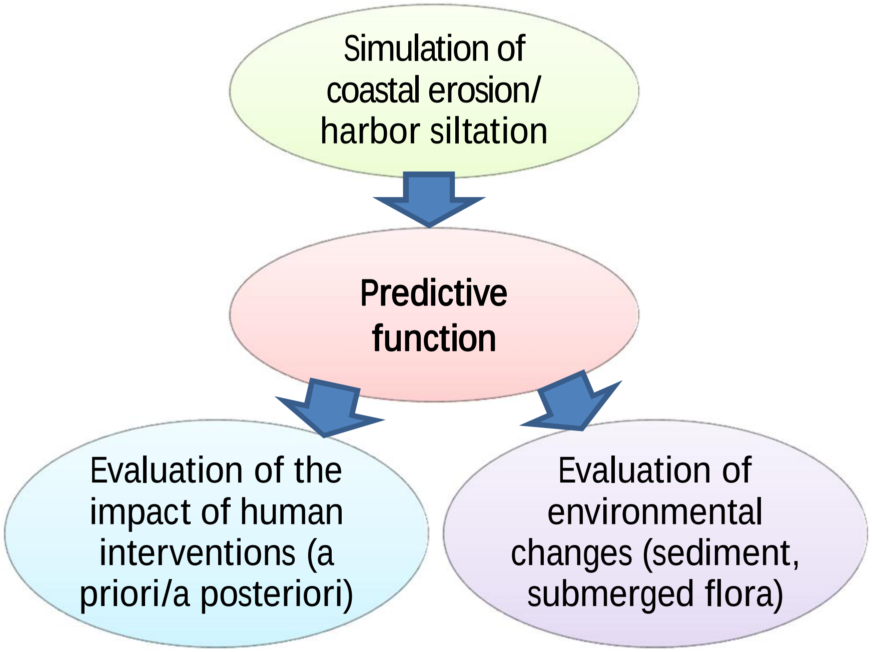

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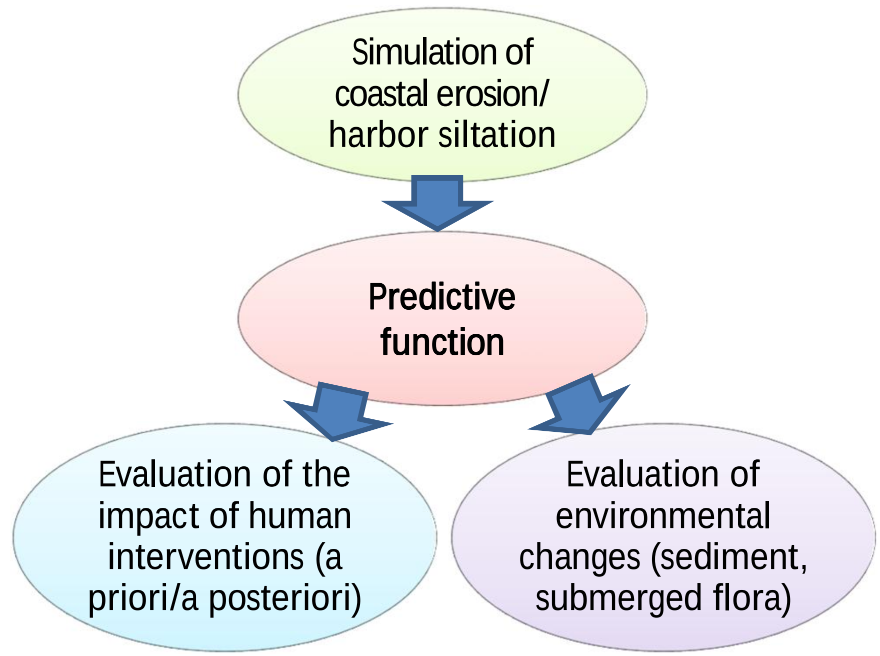

This framework has been developed in the **NEPTUNE Project**
Natural Erosion Prevision Through Use of Numerical Environment
LEGGE REGIONALE 7 AGOSTO 2007 N.7: “PROMOZIONE DELLA RICERCA SCIENTIFICA E DELL’INNOVAZIONE TECNOLOGICA IN SARDEGNA”

UNIONE EUROPEA REPUBBLICA ITALIANA REGIONE AUTONOMA DELLA SARDEGNA

Motivation and objectives

The simulation of the coastal erosion is based on a **multi-scale approach**, **coupling:**

Delft3D

the **open-source code** for the simulation of the large-scale flow and wave dynamics

ShallowBox

the **in-house developed code is used** for the evaluation of the sediment transport and costal erosion in the smaller area of interest

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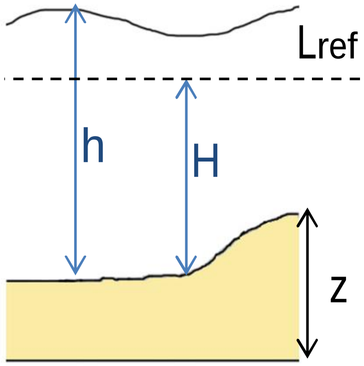
Main advantages of ShallowBox:

- The numerical formulation is based on a well-balanced finite-volume discretization for **unstructured grids,** which allow to efficiently take into account the presence of natural or engineering **solid elements of complex geometry**
- **Dry/wet treatment** permits to explicitly obtain the **evolution of the coastal line**
- **Implicit time advancing** combined with finite-volume methods in the simulation of morphodynamic flows allows a large time advancing step *(Bilanceri et al. Mathematics and Computers in Simulation 2014)*

ShallowBox: shallow water + Exner equations

ShallowBox is based on the shallow water approach.
Navier-Stokes equations are averaged in vertical direction:

$$
\begin{cases}
\dfrac{\partial h}{\partial t}+\dfrac{\partial hu}{\partial x}+\dfrac{\partial hv}{\partial y}=0 \\
\dfrac{\partial hu}{\partial t}+\dfrac{\partial}{\partial x}\left(hu^2+\dfrac{1}{2}gh^2\right)+\dfrac{\partial}{\partial y}(huv)=-gh\dfrac{\partial Z}{\partial x}-\dfrac{C_D}{gh}u\sqrt{u^2+v^2} \\
\dfrac{\partial hu}{\partial t}+\dfrac{\partial}{\partial x}(huv)+\dfrac{\partial}{\partial y}\left(hv^2+\dfrac{1}{2}gh^2\right)=-gh\dfrac{\partial Z}{\partial y}-\dfrac{C_D}{gh}v\sqrt{u^2+v^2}
\end{cases}
$$



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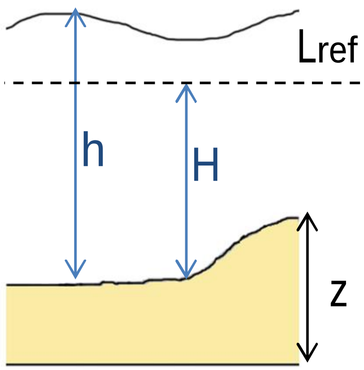

The action of the shear between the fluid and the solid surfaces is taken into account through a source friction term in the momentum equations. C_D is a function of the sedimentology of the seabed

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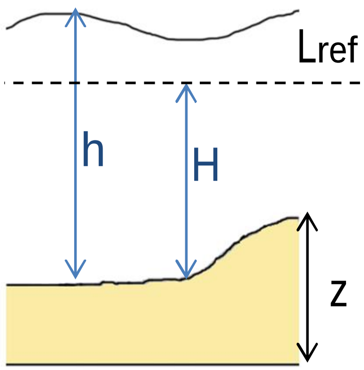

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Exner equation expresses the **conservation of the sediment volume**:

$$\frac{\partial Z}{\partial t} + \xi \boxed{\frac{\partial Q_x}{\partial x}} + \xi \boxed{\frac{\partial Q_y}{\partial y}} = 0 \qquad \text{con } \xi = \frac{1}{1-p}, \quad p = \text{ porosity of the sediment}$$

Sediment fluxes have to be modeled...

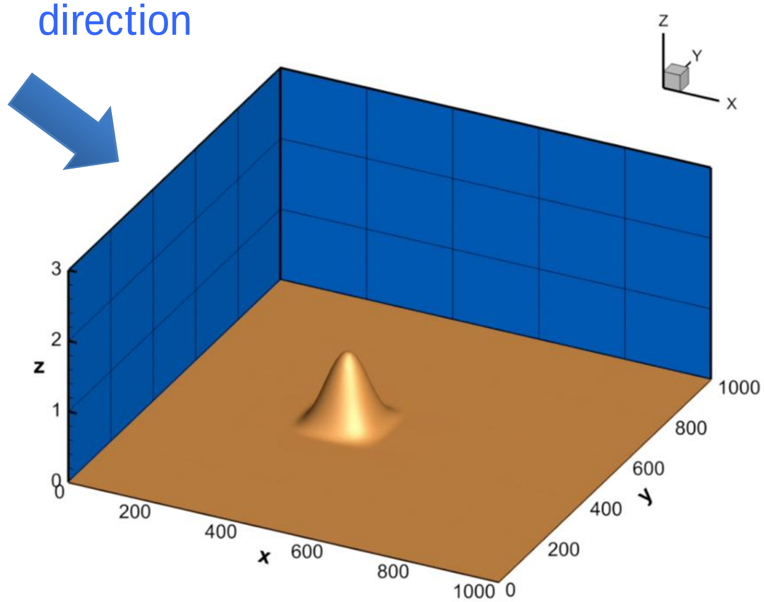
ShallowBox: sediment transport model

Meyer-Peter Müller model – Model that is widely validated and used in the literature

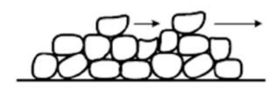
The model is based on the **critical velocity** U_{cr}

- Below the critical velocity, the seabed does not move
- Above the critical velocity, the sediment flows are expressed by a semi-empirical law

Flow direction



$$Q_i = \frac{u_i}{\|\vec{U}\|}\tilde{A}\left(\|\vec{U}\|^2 - U_{cr}^2\right)^{\frac{3}{2}}$$



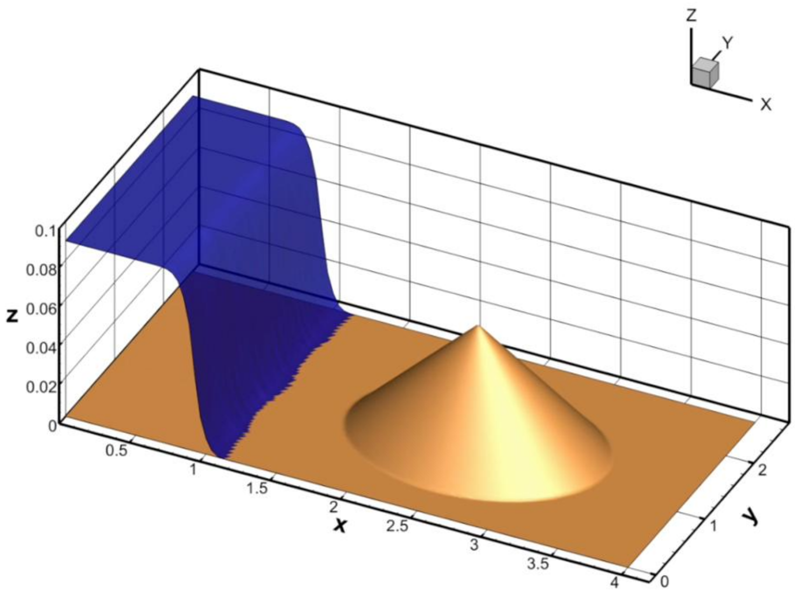
where $\tilde{A}$ e U_{cr} depend on the **characteristics of the sediment** (average diameter, density and water-bottom friction coefficient)

ShallowBox: wet/dry interface treatment

If **h<ε** the computational cell is considered **dry** otherwise **wet**. For dry cells we impose u=v=0.

Wet/dry interface

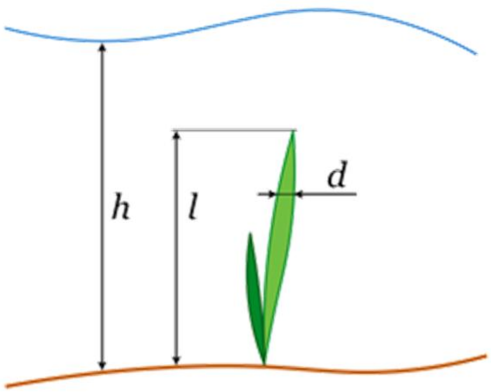
- If Z_{DRY}>$(Z+h)_{WET}$, the **dry cell can not be 'flooded'** → It is considered as a wall in the evaluation of the fluxes
- If Z_{DRY}<$(Z+h)_{WET}$, the **dry cell can be 'flooded'** → The classical scheme for the fluxes evaluation is used



The ShallowBox code has been **widely validated** on simple test cases available in the literature

ShallowBox: seagrass meadow effect

The effects of the possible presence of seagrass meadows, which are known to have a **non negligible impact on sediment transport**, are introduced in the model.



The **friction coefficient C_D** in the bedsea is **modified where the seagrass meadow is present** as a function of:

- Diameter of the seagrass meadow, *d*
- Height of the seagrass meadow, *l*
- Ratio between the height of the seagrass meadow and the water depth, *l/h*

The friction drag can be also derived from **experimental measurements** in the area of interest and directly introduced as an input parameter in the ShallowBox code.

Moreover, **no sediment trasportation** is allowed in the region **where the seagrass meadow is present**

Multi-scale simulations strategy

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Historical or experimental database:

- bathymetry (submerged and coast line)
- characteristics of the sediment
- wave motion (height, peak period, direction)
- wind velocity and direction

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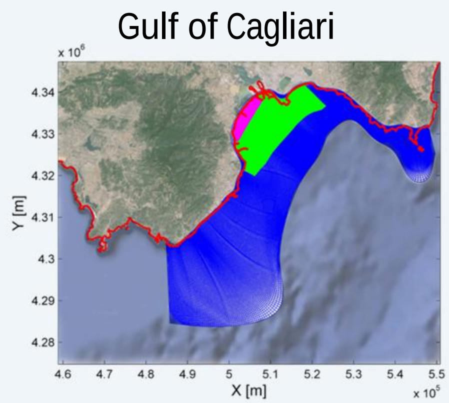
Delft3D

Large-scale flow and wave motion
(without coastal erosion)



- Initial velocity and water depth fields
- Boundary conditions: flow rate vs. time

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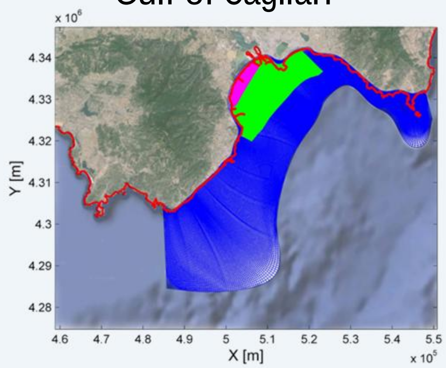
Gulf of Cagliari



- Initial velocity and water depth fields
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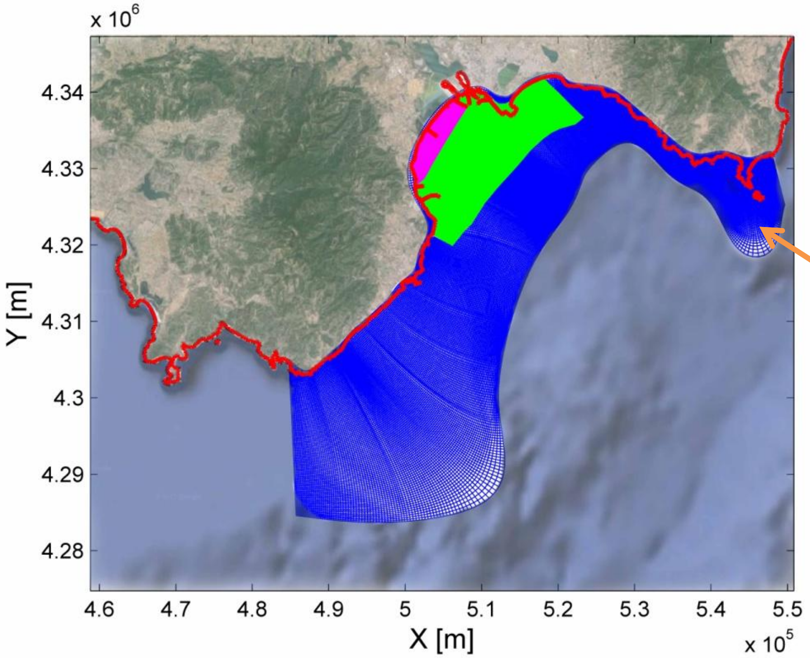
ShallowBox

Coastal erosion prediction

- Evaluation of the sediment transport
- Evaluation of the coast line evolution
- Effect of the Rumianca pier (simulation with and without the pier)
- Effect of the seagrass meadow

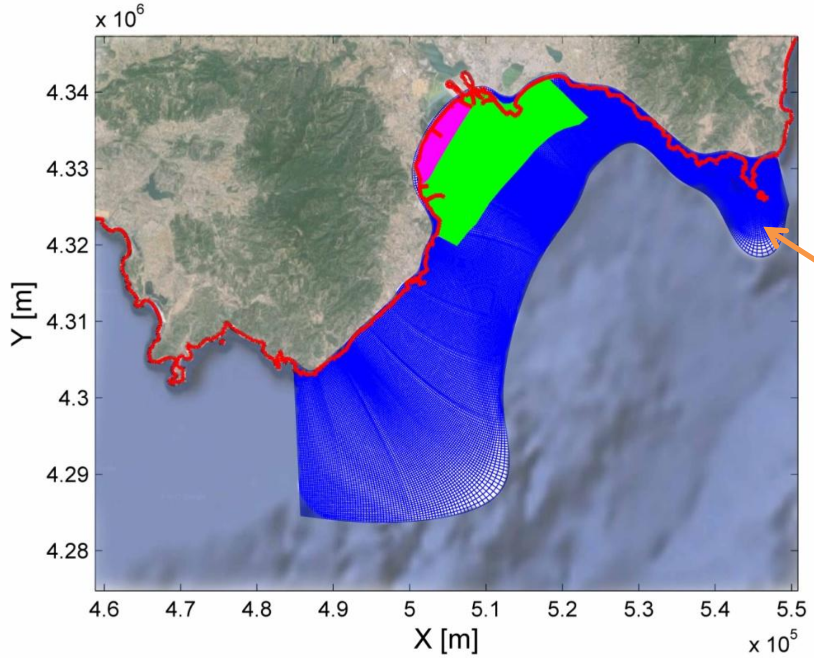
Delft3D: large-scale simulations



Simulation of the **wave motion** in the whole area of the **Gulf of Cagliari**, using three computational grids, which are progressively more refined

Wave data from the **wavemeter** of the Rete Ondametrica Nazionale (ISPRA)

Delft3D: large-scale simulations



Simulation of the **wave motion** in the whole area of the **Gulf of Cagliari**, using three computational grids, which are progressively more refined

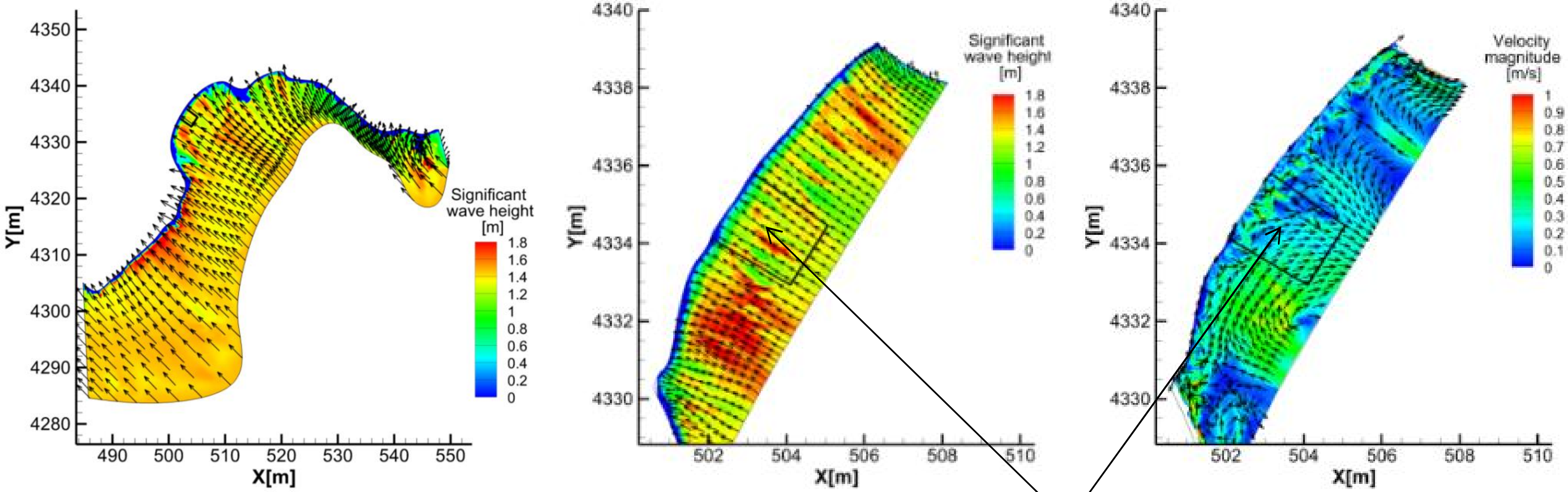
Wave data from the **wavemeter** of the Rete Ondametrica Nazionale (ISPRA)

Two significant events are selected, for which the boundary conditions for the ShallowBox simulations are realized.

Significant height of the wave [m]	Peak period of the wave [s]	Wave direction [deg]	Wind velocity [m/s]	Wind direction [deg]	Time length [h]
3.0	**6.0**	**135**	**3.3**	**135**	**30**
1.7	11.43	219	10.1	302	155.5
3.41	**7.24**	**193**	**4.4**	**322**	**56.5**
4.3	11.21	144	3.3	314	24
2.93	8.47	184	7.0	113	63.5
1.91	7.46	180	7.0	307	125.5

Delft3D: large-scale results for the event #1

Significant height and direction of the wave **Velocity fields**



Area considered in ShallowBox small-scale simulations

Characteristics of the event #1

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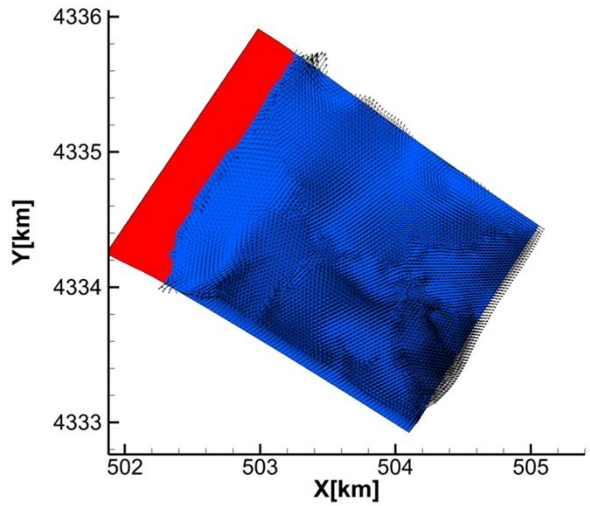
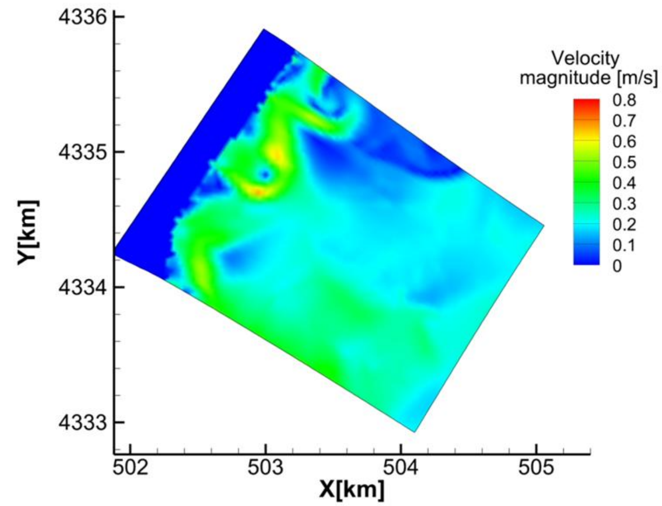
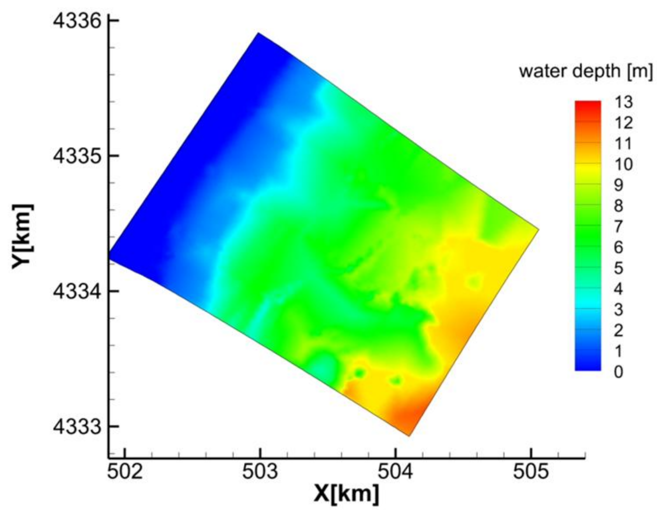
Velocity vectors and coast line



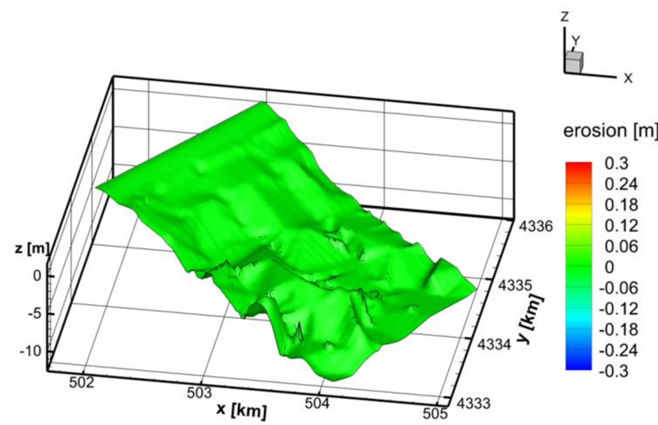
Velocity magnitude



Water depth

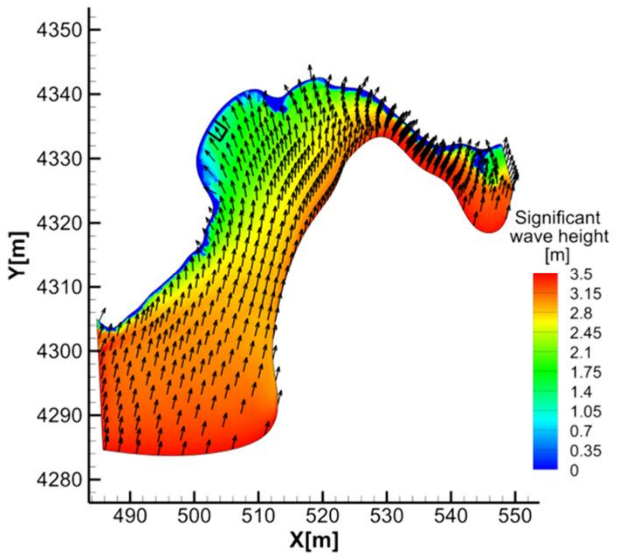


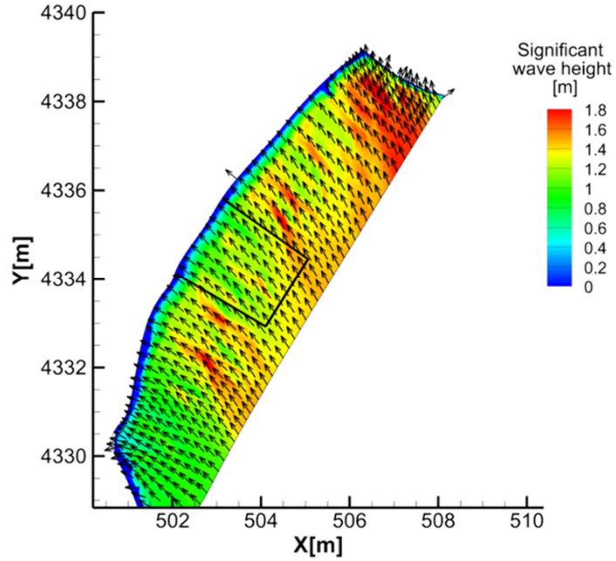
Coast erosion



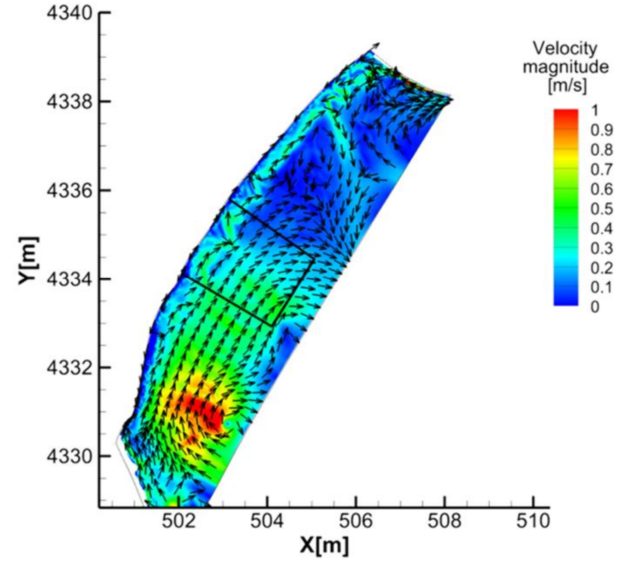
Delft3D: large-scale results for the event #2

Significant height and direction of the wave





Velocity fields



Characteristics of the event #2

Significant height of the wave [m]	Peak period of the wave [s]	Wave direction [deg]	Wind velocity [m/s]	Wind direction [deg]	Time length [h]
3.41	**7.24**	**193**	**4.4**	**322**	**56.5**

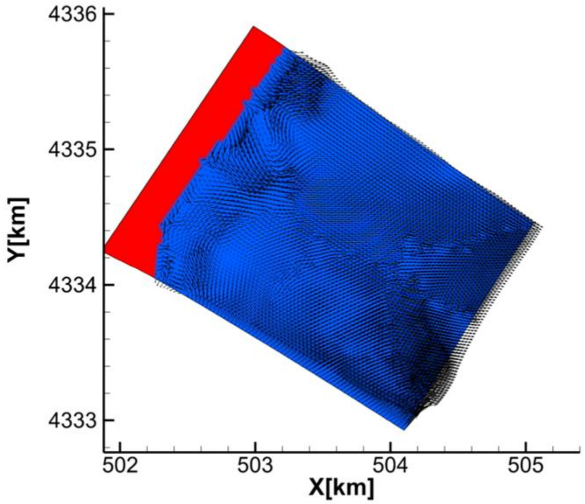
Considered simulation

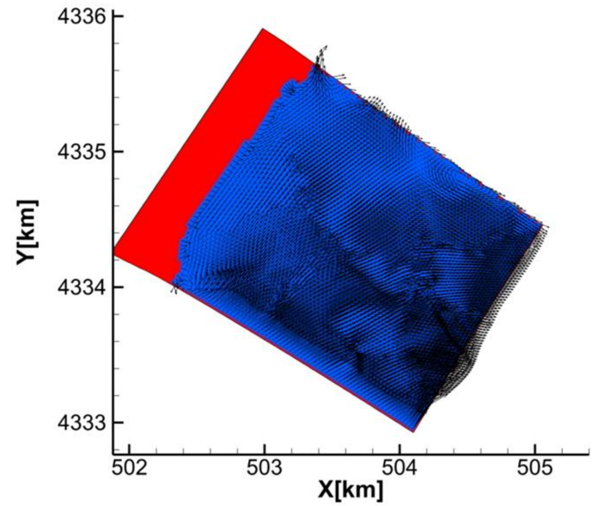
- **Event #2:** event #2 starts from the same bathymetry as for the event #1
- **Event #1 followed by event #2**: event #2 starts from the bathymetry previously modified by the event #1

ShallowBox: small-scale results for the event #2

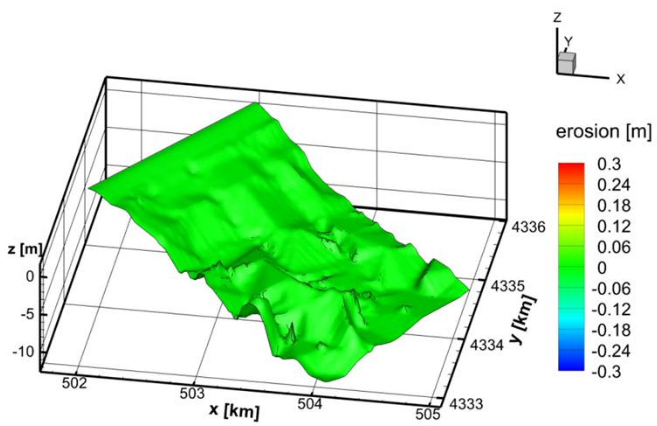
Simulation of the **event #2**

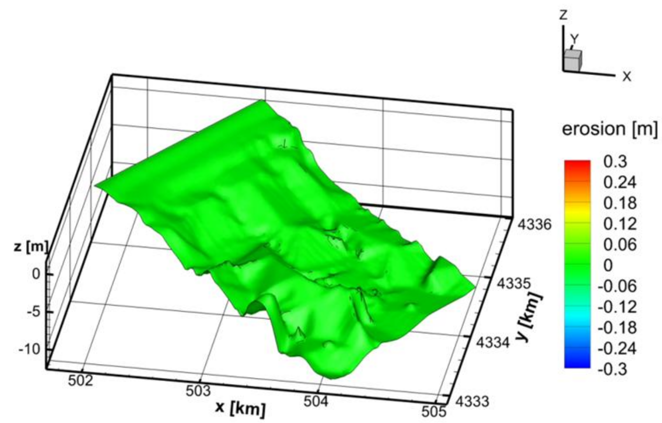
Simulation **of the event #1 followed by event #2**





Velocity vectors and coast line

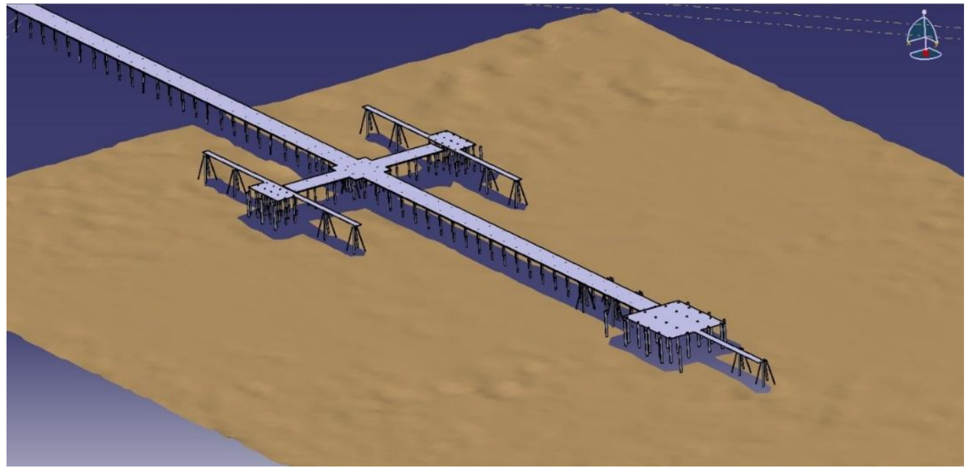




Coastal erosion

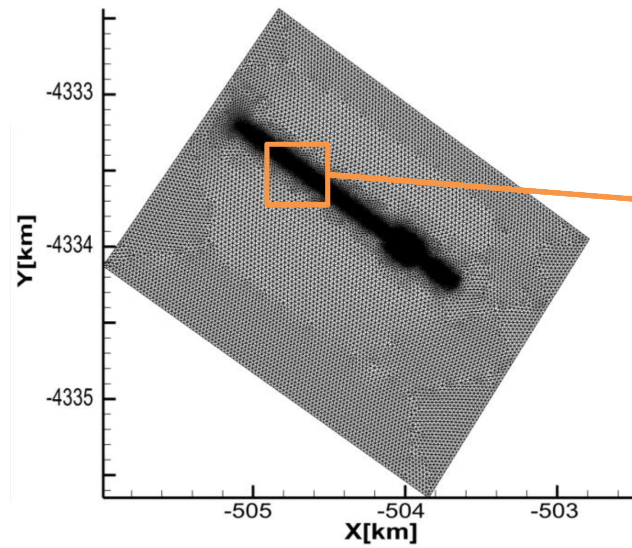
ShallowBox: impact of human interventions

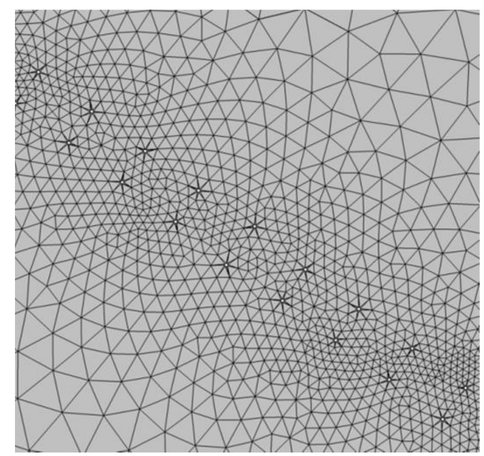
Effect of **Rumianca pier on hydrodynamics and coastal erosion**



Refined unstructured computational grid (33000 nodes)

The flow dynamics around the pylons of the pier has to be resolved

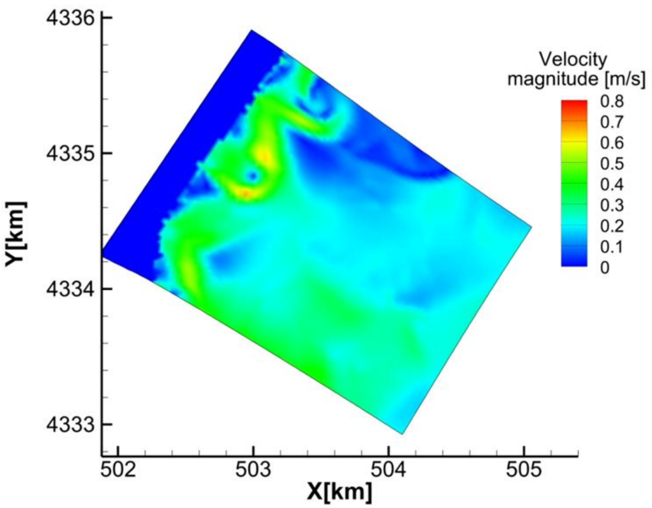


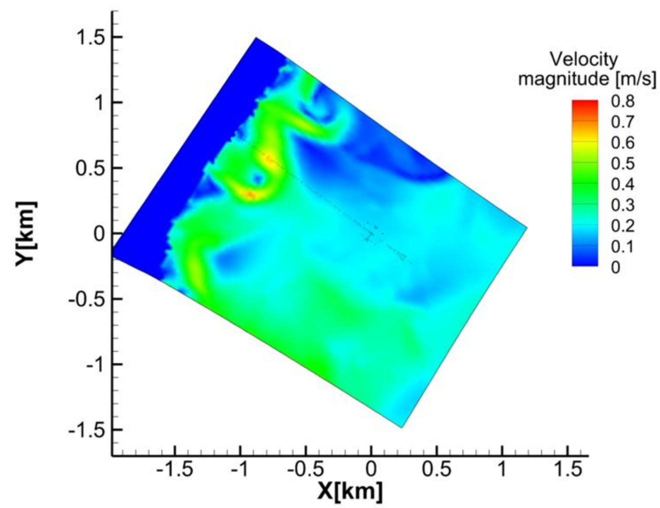


ShallowBox: effect of the Rumianca pier (event #1)

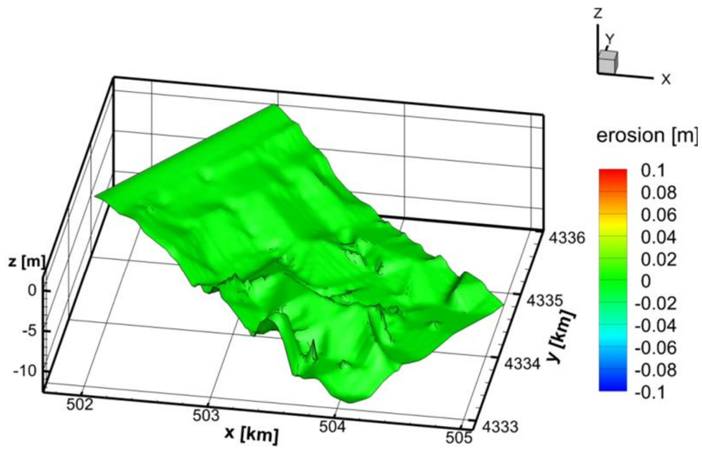
Simulation **without the pier**

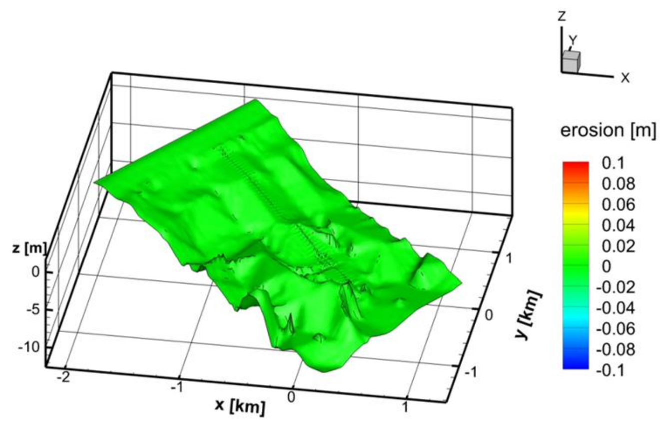
Simulation **with the pier**





Velocity magnitude: the wake of the pylons of the pier is clearly visible

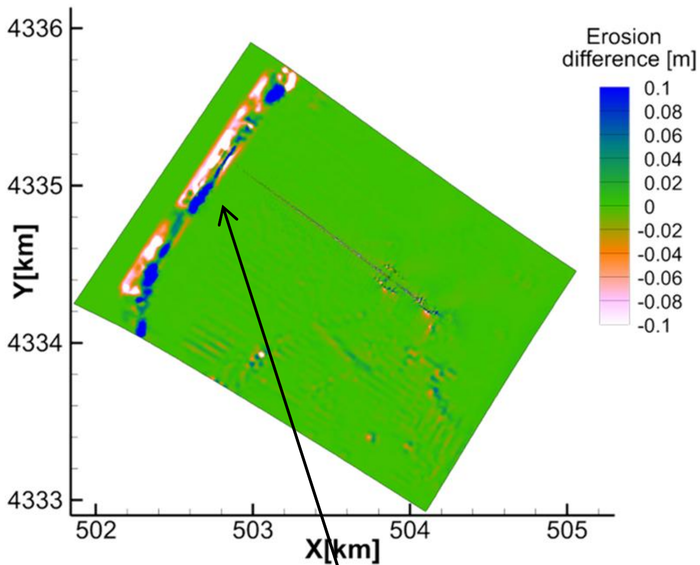




Coastal erosion: less sediment deposition along the coast line when the pier is present

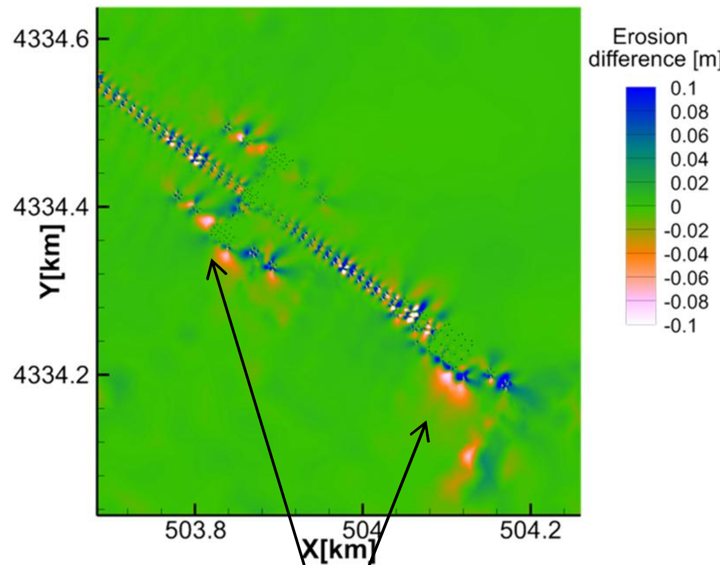
ShallowBox: effect of the Rumianca pier (event #1)

Coastal erosion difference
(with pier – without pier)



Less sediment deposition along the coast line when the pier is present (some centimeters of difference in a event of few hours length)

Coastal erosion difference
(with pier – without pier)

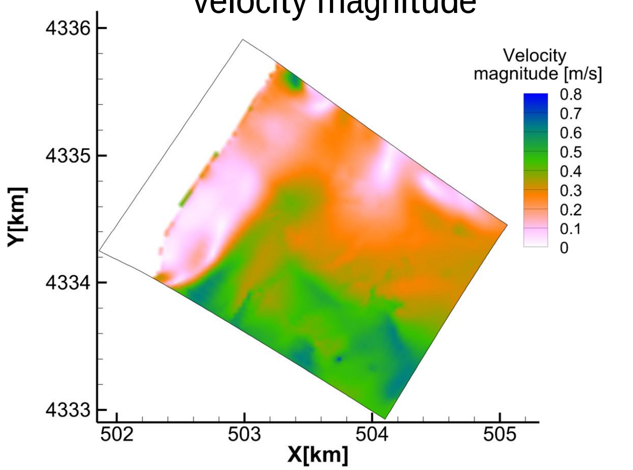


Local effect on sediment transport due to the presence of the **pylons of the pier**

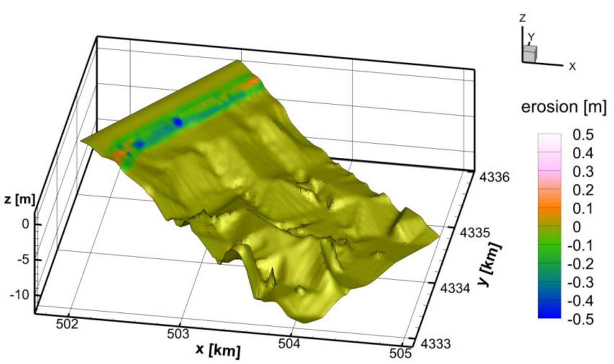
ShallowBox: effect of the seagrass meadows

Simulation **without the seagrass**

Velocity magnitude

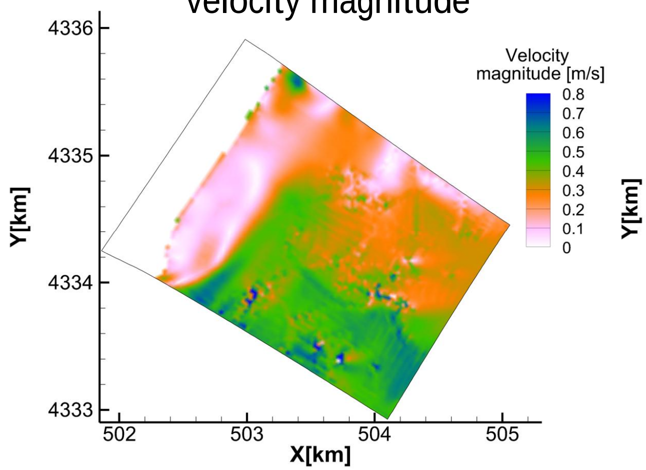


Coastal erosion

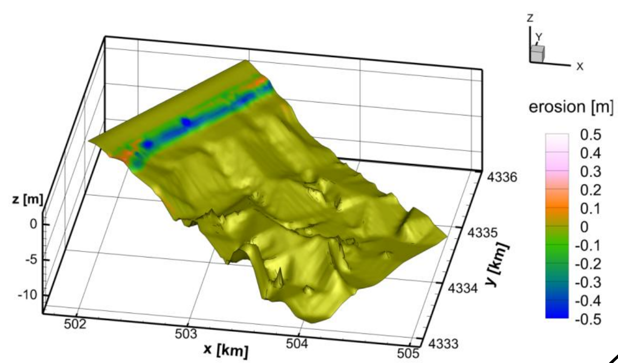


Simulation **with the seagrass**

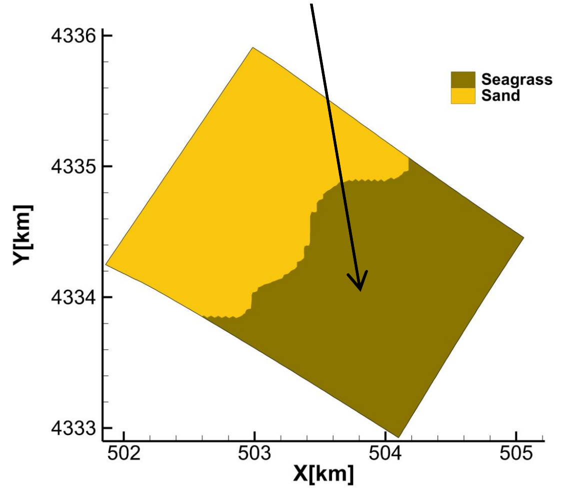
Velocity magnitude



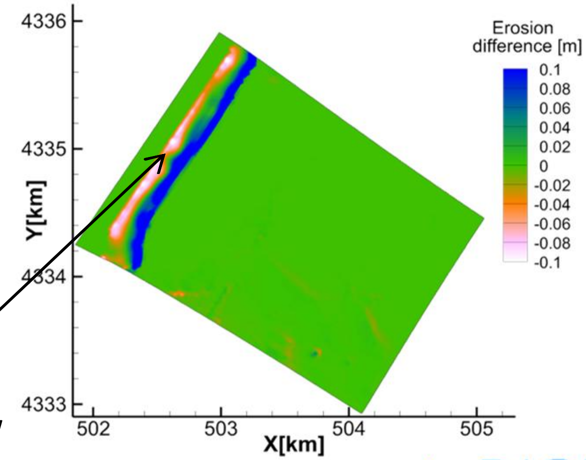
Coastal erosion



Region where the seagrass meadow is experimentally found



Erosion difference



More sediment deposition along the coast line with the seagrass meadow

Conclusions

Predictive function of the multiscale simulations **Delft3D+ShallowBox**

Effect of the type of seabed (e.g. seagrass Meadows)

Simulation of coastal erosion/ harbor siltation

Effect of human interventions along the coastline (pier, wharf...)

Environmental impact

- **A priori** evaluation of the impact of **human interventions**
- **Evaluation of environmental changes** (sediment type, submerged flora)

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Future developments
(planned in the NEPTUNE2 framework…)

Change/refinement of morphodynamic models (e.g. run-up models)

Improvement of the ShallowBox interface with the large-scale code and the experimental data

Dispersion of polluting substances

Conclusions

Predictive function of the multiscale simulations **Delft3D+ShallowBox**

Effect of the type of seabed (e.g. seagrass Meadows)

Simulation of coastal erosion/ harbor siltation

Effect of human interventions along the coastline (pier, wharf…)

Environmental impact

- **A priori** evaluation of the impact of **human interventions**
- **Evaluation of environmental changes** (sediment type, submerged flora)

Future developments

(planned in the NEPTUNE2 framework…)

Change/refinement of morphodynamic models (e.g. run-up models)

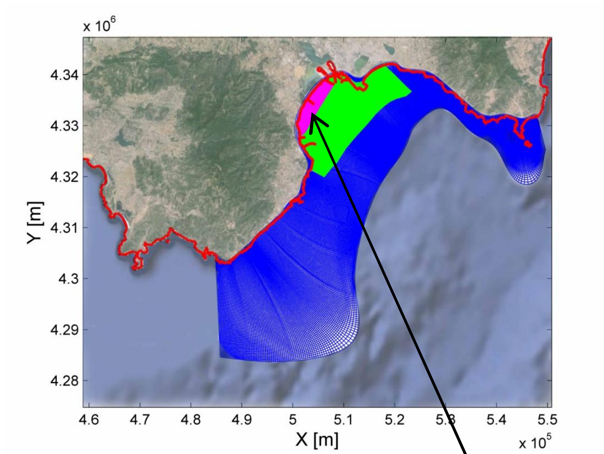
Improvement of the ShallowBox interface with the large-scale code and the experimental data

Dispersion of polluting substances

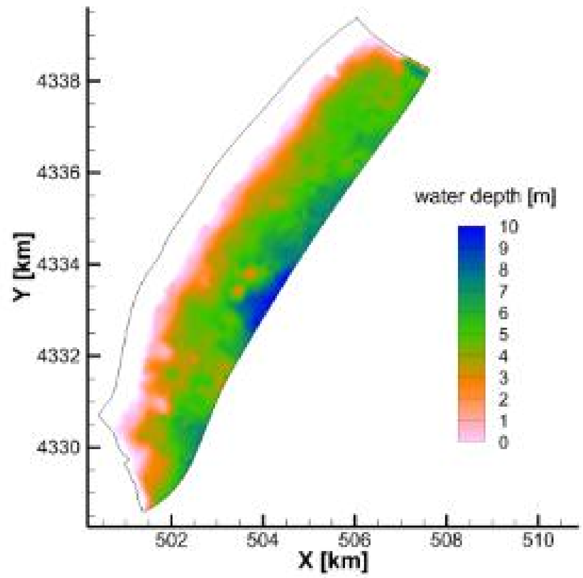
Thank you for the attention!

Extra slides

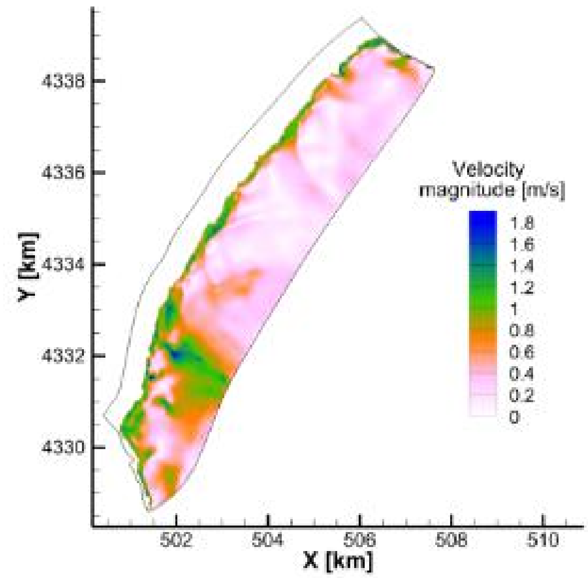
ShallowBox: medium-scale simulations



water depth



velocity magnitude



Shallow box can be successfully used also for the simulation of larger areas of interest, still maintaining the multiscale approach with a large-scale code