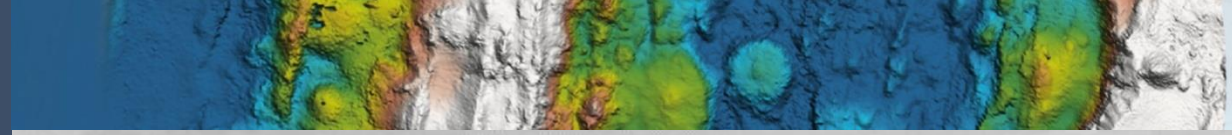

6as Jornadas de Engenharia Hidrográfica

1as Jornadas Luso-Espanholas de Hidrografia

Modelos hidromorfodinâmicos para simulação de estuários em cenários ambientais futuros

I. Iglesias, J.L. Pinho, A. Bio, P. Avilez-Valente, W. Melo, J.M. Vieira, L. Bastos, F. Veloso-Gomes

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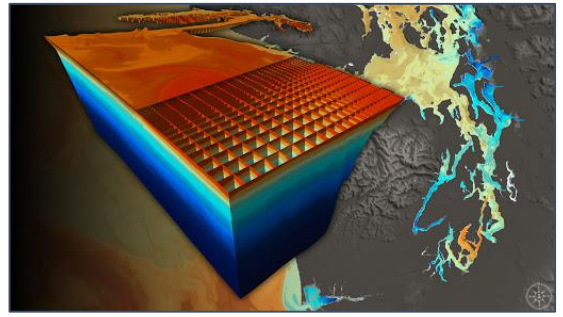
Background

Estuaries:

- **Highly populated** regions
- **Complex interfaces** between rivers and coasts
- **Complex** physical, morphological, geological, chemical and biological **processes**
- Important **ecosystem services**: relevant environmental, economic and societal importance
- **Vulnerable** regions: extreme events, climate change, anthropogenic activities



Numerical modelling to:

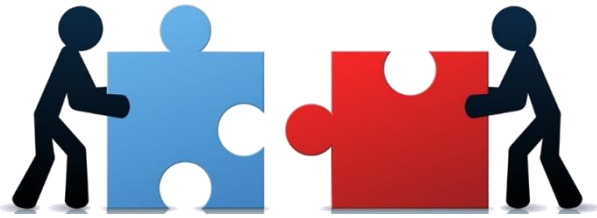
- assess estuarine **behavior**
- support an effective and integrated **management**
- promote the **security** of populations and the **sustainability** of marine ecosystems and services
- characterize **risk** areas and create impact assessment tools

Background

Numerical models:

- Computational resources + complex numerical models => **Accurate** high-resolution studies
- **However**:
  - Modeling systems have advantages and limitations.
  - Model solutions can display uncertainties related with errors, calibration parameters, model assumptions and forcing functions.
  - Models can have biases, high variability, or inaccuracies related with initial conditions or the representation of physical processes.
- This cause **uncertainties** in numerical prediction systems => diminish the results reliability.
- Given the need for accurate forecasts, finding and implementing new solutions to avoid such errors is crucial.
- **Why not use several models to reduce uncertainties?**

Background



Ensembles technique:

- Ensemble is a French word that means "**together**", referring to a unit or group of complementary parts that contribute to a single effect.
- The technique consists of running two or more related numerical models with different structural complexities but with the same initial and forcing conditions.
- Results are synthesized in a single solution using statistical tools, which will improve the accuracy of the final forecast when compared with the solutions obtained individually.

EsCo-Ensembles project:

- The main **objective** of the EsCo-Ensembles project (FCT: 2018-2021) is to improve predictions of hydro-morphodynamic patterns with the **ensembles technique** to:
  - provide a complete hydro-morphodynamic characterization;
  - assess future trends;
  - understand the distribution of biota and the functioning of ecosystems;
  - estimate the risks of floods in the face of rising sea levels associated with global warming.

Background

Minho Estuary:

- International river with very shallow mesotidal estuary
- Reference in ecotoxicological studies
- Low impacted estuary (low human intervention)
- Large diversity of habitats and biodiversity
- Dynamics essentially unknown
- Silting => High degree of sedimentation
- Artificial river flow (Frieira dam)

LTER NETWORK

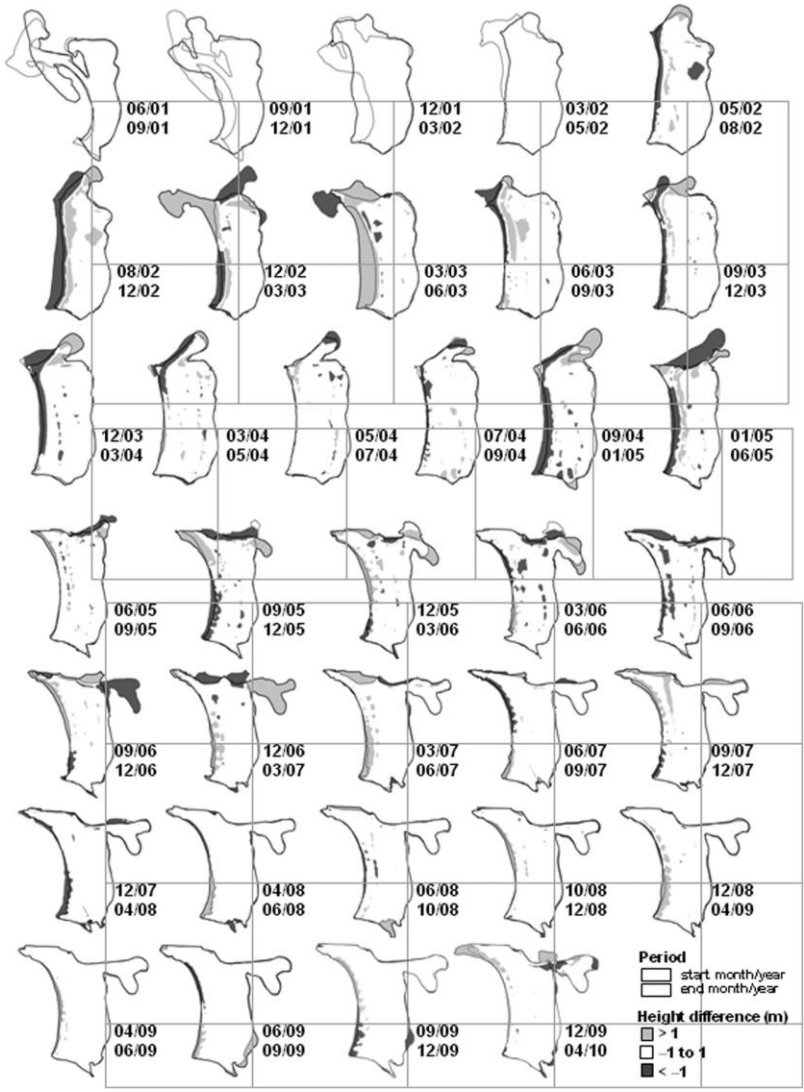
NATURA 2000

Background

Douro Estuary:

- Mesotidal narrow urban estuary
- Highly populated margins
- São Paio Bay Nature Reserve
- Dynamics forced by freshwater flows
- Strong currents
- Recurrent severe floods
- Estuarine sand spit evolution due to breakwaters construction
- Artificial river flow (Crestuma-Lever dam)

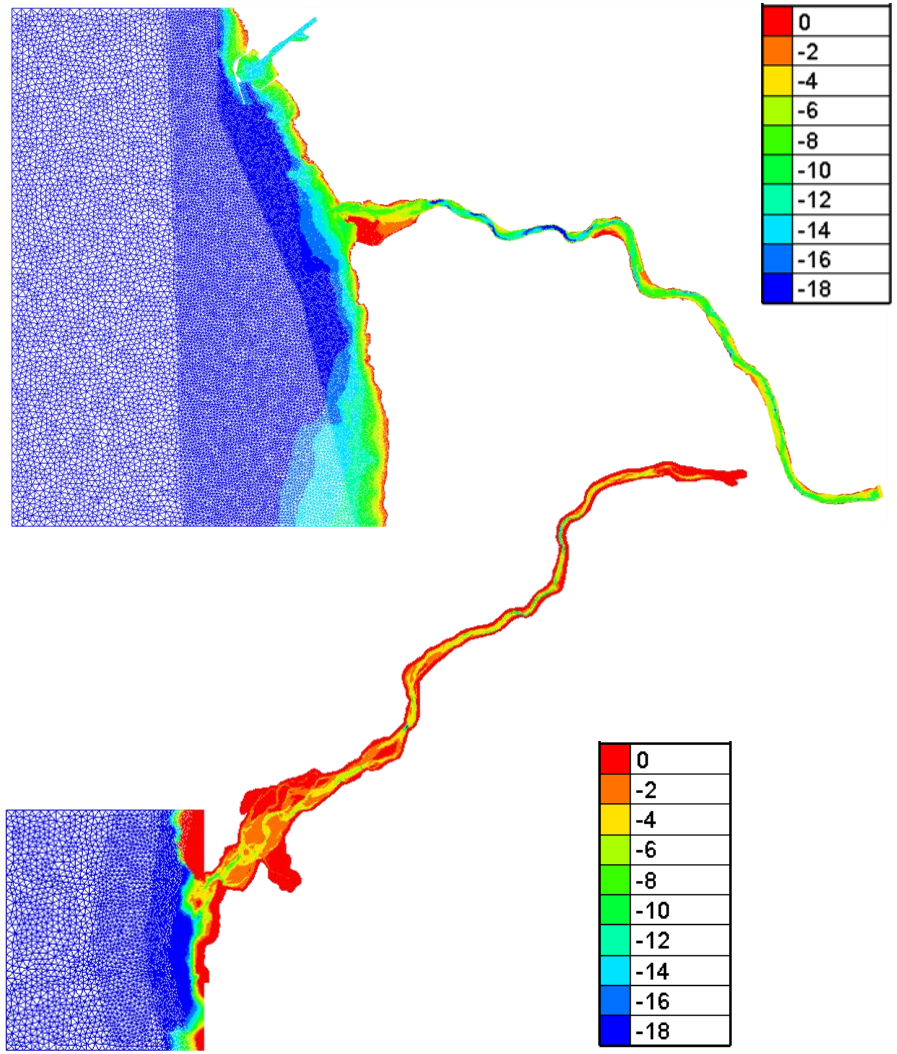
Bastos et al. (2012)



Bastos, L., Bio, A., Pinho, J.L., Granja, H., da Silva, A. (2012). Dynamics of the Douro estuary sand spit before and after breakwater construction. Estuarine and Coastal Shelf Science, 109, 53–69.

Numerical models

- 2DH depth averaged estuarine modules from Delft3D and openTELEMAC-MASCARET (OTM) already validated at Iglesias et al. (2019a), Iglesias et al. (2019b) and Melo et al. (2020)
- Bathymetric dataset:
  - **Douro:** Estuarine bathymetry (IH; 2002 and 2009) + Coastal bathymetry (IH; 2012) + GEBCO (open ocean) + Elevation data for the sandbar (Bastos et al., 2012; 2015)
  - **Minho:** Estuarine bathymetry (ECOIS project, IH; 2006) + GEBCO (open ocean) + Topographic data (DGT; 2011)
- Grid resolution inside the estuaries: 25 – 30 m



Iglesias, I., Venancio, S., Pinho, J.L., Avilez-Valente, P., Vieira, J. (2019a). Two models solutions for the Douro Estuary: flood risk assessment and breakwater effects. Estuaries and Coasts, 42(2), 348-364.

Iglesias, I., Avilez-Valente, P., Bio, A., Bastos L. (2019b). Modelling the main hydrodynamic patterns in shallow water estuaries: The Minho case study. Water, 11(5), 1040, 1-25.

Melo, W., Pinho, J., Iglesias, I., Bio, A., Avilez-Valente, P., Vieira, J., Bastos, L., Veloso-Gomes, F. (2020). Hydro- and Morphodynamic Impacts of Sea Level Rise: The Minho Estuary Case Study. Journal of Marine Science and Engineering, 8(6), 441.

Numerical models

Parameter	Delft3D		OTM	
	Minho	Douro	Minho	Douro
Time step	1 min	6 s		
Spin up	6 h			
Land areas	Wet-dry zones			
Horizontal eddy viscosity and diffusivity coefficients	3 $m^2 \cdot s^{-1}$		1 $m^2 \cdot s^{-1}$	
Bottom friction	Manning 0.019 s $m^{-1/3.}$ (upp. est.) 0.026 s $m^{-1/3.}$ (low. est.)	Manning = 0.04 s $m^{-1/3.}$	Chézy = 53 $m^{1/2}$ s^{-1}	Strickler = 33 $m^{1/3}$ s^{-1}
Tide level	Main tidal constituents: M2, S2, N2 and K2		TPXO2	
Salinity and temperature	Winter conditions: 0 PSU and 8 ºC for the river boundary; 35.8 PSU and 17 ºC at the ocean boundary			

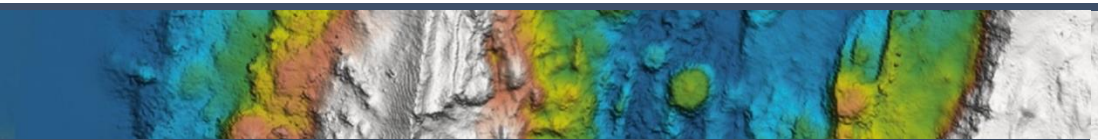
Numerical models

- River flow data from Foz do Mouro (Minho) and Crestuma-Lever (Douro) was selected.
- It was assumed that the flow probability distributions follow a Gumbel distribution.
- Peak flow rates were calculated for return periods of 100 and 1000 years.

Numerical simulations	Return period (years)	River flow (m^3/s)		Scenario	Oceanic elevation (m)
		Minho	Douro		
S1	100	6038	17634	Historic	3.0
S2		6038	17634	RCP 4.5 2100	3.5
S3		6038	17634	RCP 8.5 2100	3.7
S4	1000	8262	24629	Historic	3.3
S5		8262	24629	RCP 4.5 2100	3.7
S6		8262	24629	RCP 8.5 2100	4

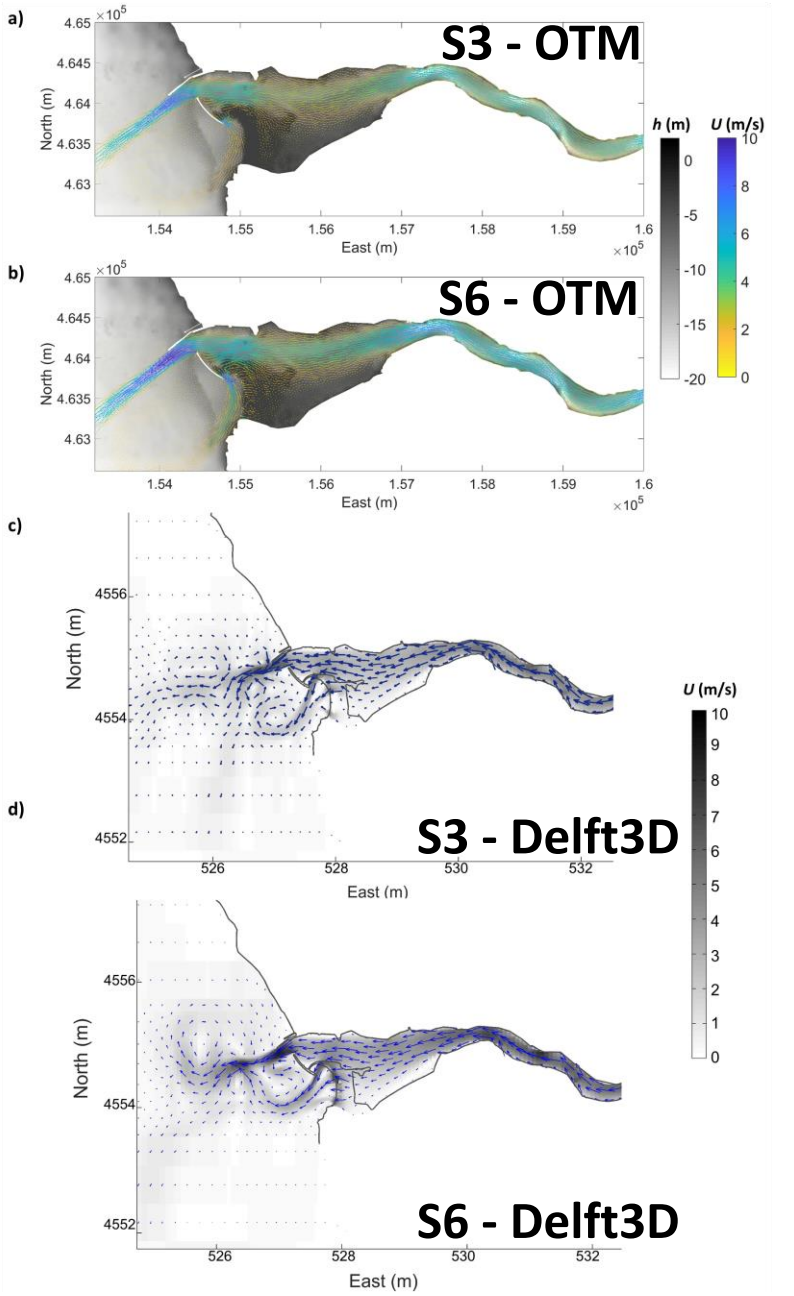
- Possible changes in peak flow rates due to changes in future precipitation conditions in the basin or in the operation of dams during extreme events were not considered.
- The elevation on the ocean frontier was introduced as a constant value, considering the extreme values of sea level calculated by Vousdoukas et al. (2017).
- Extreme values of sea level include: rising sea level, tide, wave set-up and storm surge.
- The results of the simulations are processed when a permanent regime is reached.

Vousdoukas, M.I., Mentaschi, L., Voukouvalas, E., Verlaan, M., Feyen, L. (2017). Extreme sea levels on the rise along Europe's coasts. Earth's Future, 5, 304-323.



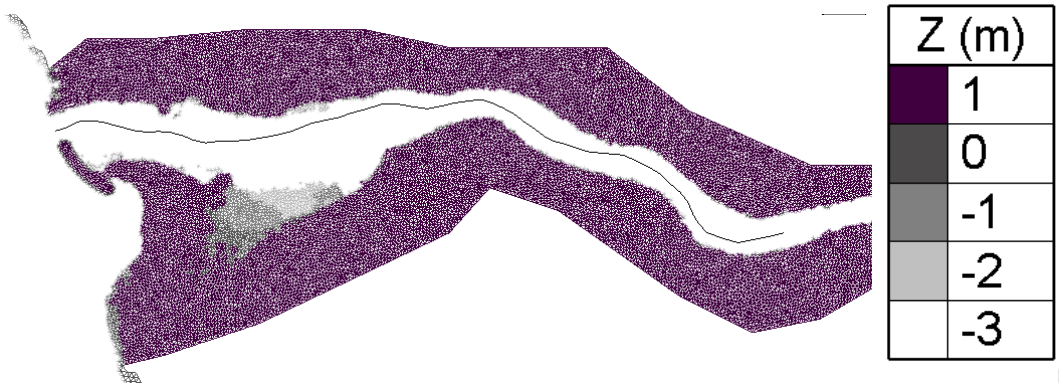
Results: Douro

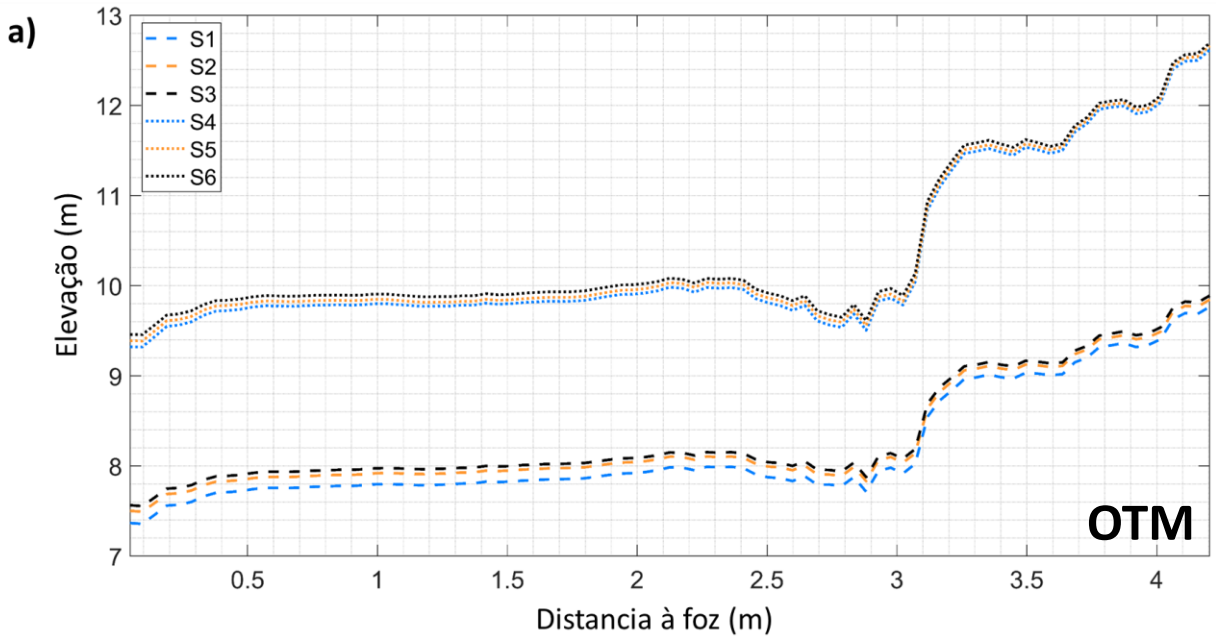
- Oceanic elevation influence in current velocity fields is not observed.
- Current velocity fields vary with the imposed river flow.
- The stronger differences in the current velocities between the simulations that considered river flow associated with 100 and 1000 years return periods are observed between the north jetty and the highlighted breakwater, as well as inside the estuary.
- Both models (OTM and Delft3D) present a similar behavior in terms of current velocity distribution and magnitude.
- Models differences arise on the sand bar region. Delft3D shows an overtopping of this structure for the two river flows considered. OTM only presents it with river flows associated with 1000-year return periods.

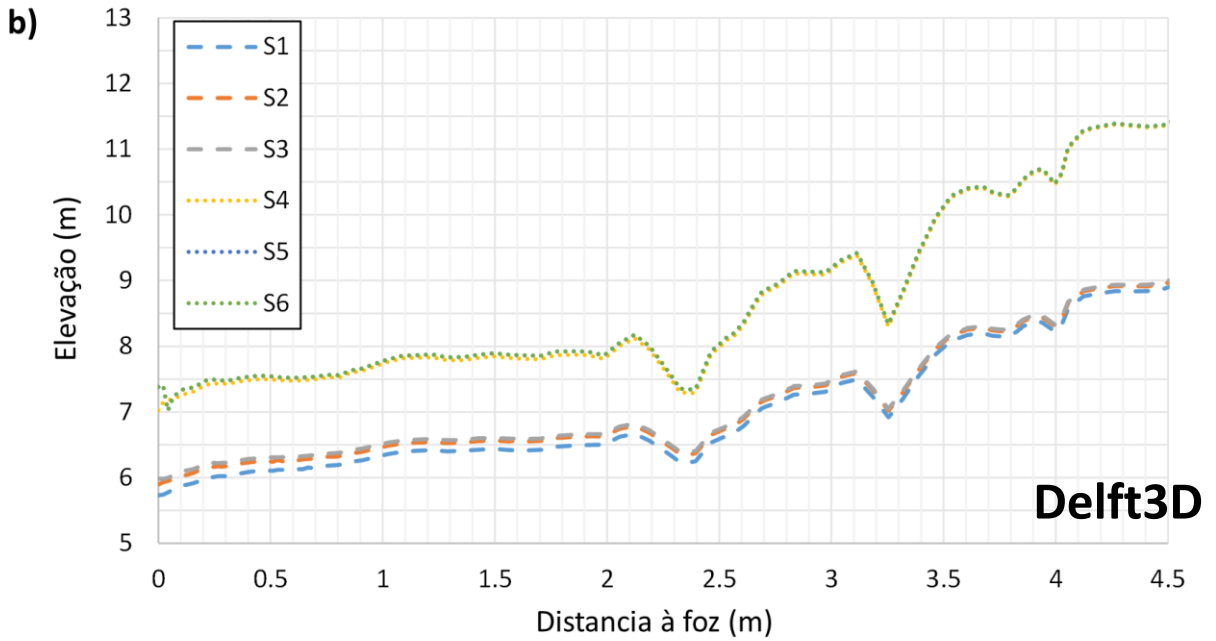


Results: Douro

- Longitudinal profiles of free surface elevation show again differences between scenarios associated with river flow and not with oceanic elevation.
- Scenarios that present the same river flow also present the same behavior.
- The two models show similar behavior but with an average difference of 1 m.

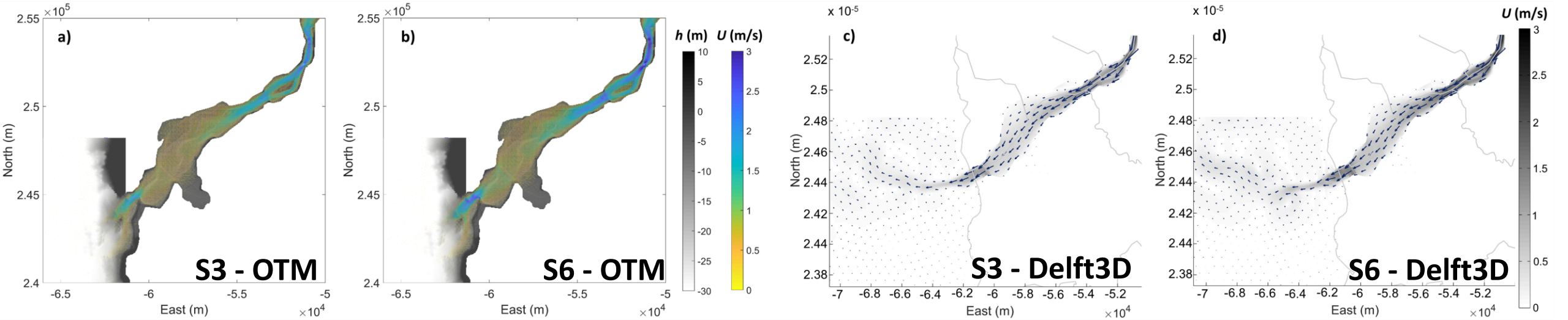






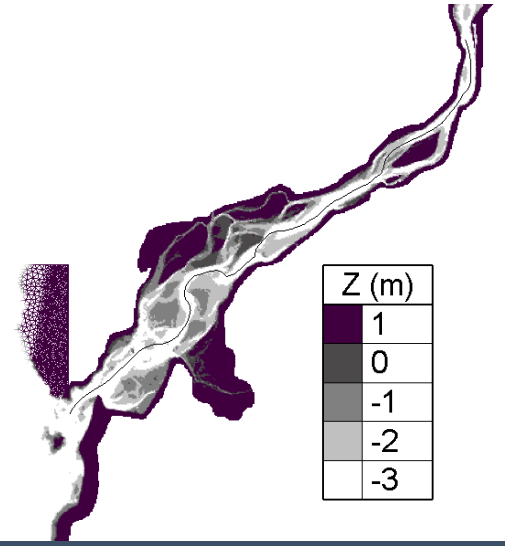
Results: Minho

- Differences in the current velocity are also mainly associated with the imposed river flow and not with the elevation imposed on the ocean boundary
- The differences are more significant in the narrower areas (mouth and areas upstream and downstream of the Boega island.
- Both models present similar behavior.

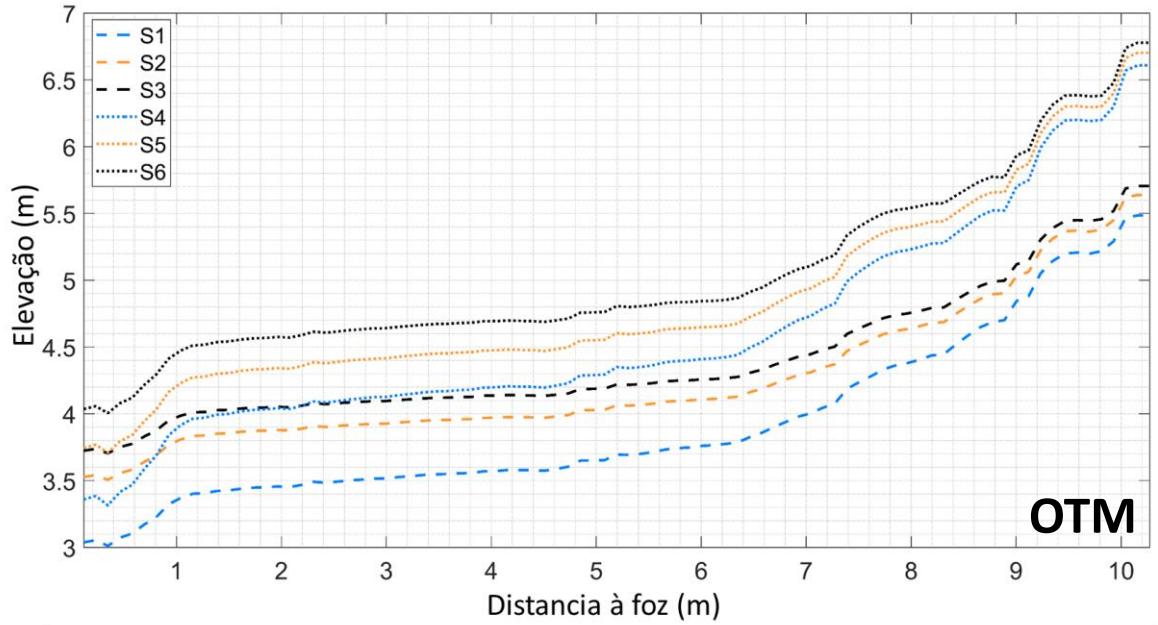


Results: Minho

- Longitudinal profiles revealed differences on free surface elevation associated with c.c. scenarios.
- Most evident in the low estuary, downstream from the island of Boega (~ 8.5 km).
- Why? Lower flood flows + estuarine morphology (widening upstream estuarine mouth).
- Both models present similar results but Delft3D elevations are slightly lower than OTM results.



a)



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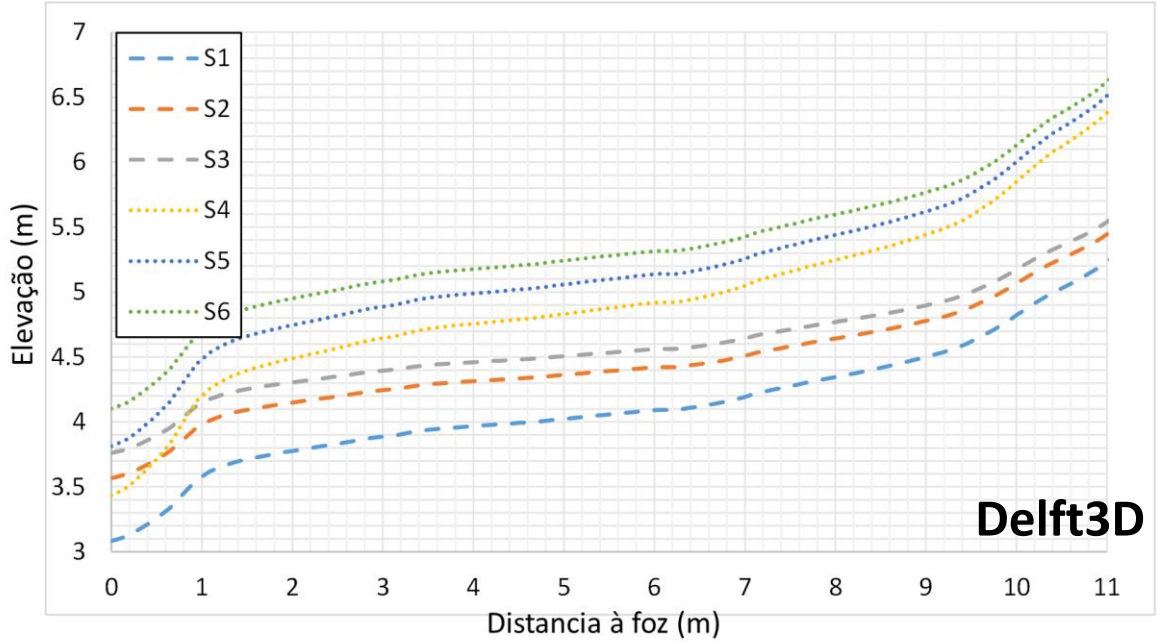

Conclusions

- For the **Douro** estuary:
  - **River dominated** estuary => Sea rising is attenuated when considering the occurrence of floods.
  - The represented scenarios demonstrated that the simulated flows can produce economic losses and material damage on its banks.
- For the **Minho** estuary:
  - **Tide dominated** estuary => The average increase in sea level will reduce the speed of the currents but will increase the flooded areas.
  - A significant worsening of the flooding level associated with extreme events and rising sea levels in this estuary is expected.
- The ensembles technique, already applied in Iglesias et al. (2019a), has shown that this approach improves the consistency of the predictions contributing to a correct current hydro-morphodynamic characterization of the studied estuaries.
- This technique will be applied after the models are refined, providing a single solution to represent their future evolution and the effect of extreme events and climate change in these two estuarine regions.

Acknowledgments

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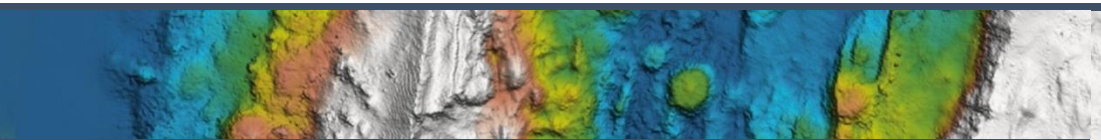

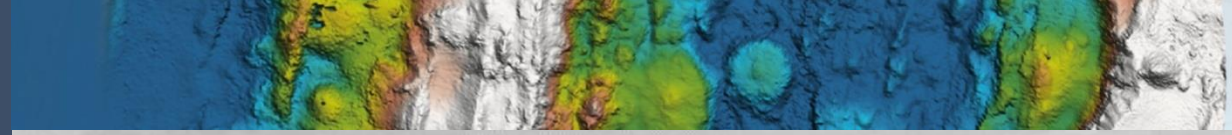

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Thank You!

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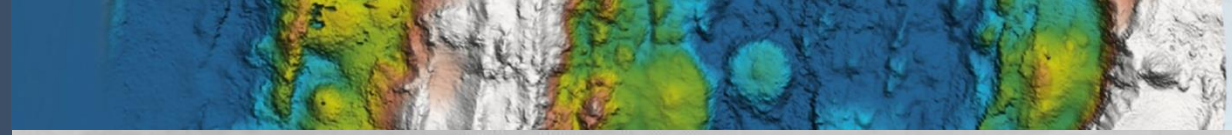

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