FLOODING OF ESTUARINE MARGINS: PROBLEMS, PROCESSES AND PREDICTIONS

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Outline

The problem

why should we care about the inundation of estuarine margins?

The processes

what drives the inundation of estuarine margins?

The predictions

can we forecast the inundation of estuarine margins?

Closure

take-home messages

The problem: vulnerability and hazard

- Many large cities are close to estuaries and thus vulnerable to estuarine inundations:
  - World: Tokio, Shanghai, São Paulo
  - Europe: London, Istanbul, Hamburg
  - Portugal: Lisbon, Oporto, Vila Nova de Gaia
- Climate change is increasing the hazard through:
  - Sea level rise
  - Growing storminess in many parts of the world (Muis et al., 2023)
  - Increasing variability of the river flow

The problem: example of the Tagus estuary


Trancão, 1967


Ribeira do Jamor, 1967


Seixal, 21/01/1996


Praia do Alfeite, 29/01/2006


Alcochete, 27/02/2010
http://www.youtube.com/watch?v=txvwoxcpEco

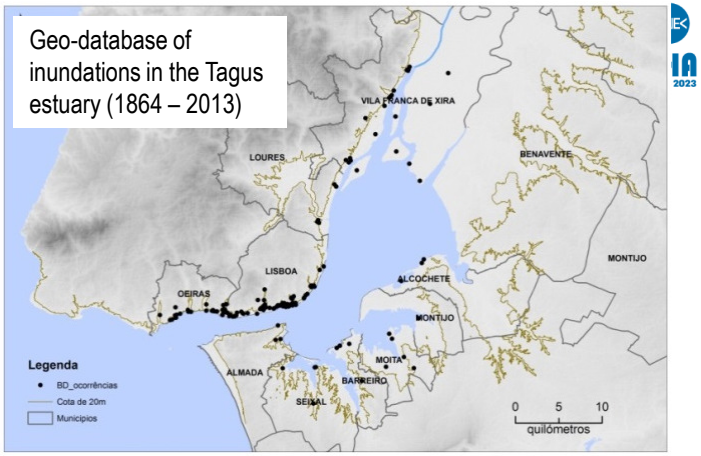

Cais do Sodré, Out 2011
Source: APL


Seixal, 10/09/2014


Caparica, feb 2014

Historical events

26%: probability of occurrence of at least one inundation event in the margins of the Tagus estuary in a year



Rilo et al., 2017

February 15, 1941

Severe human (28 casualties, 14 injured, 125 evacuees) and material damage

February 27, 2010

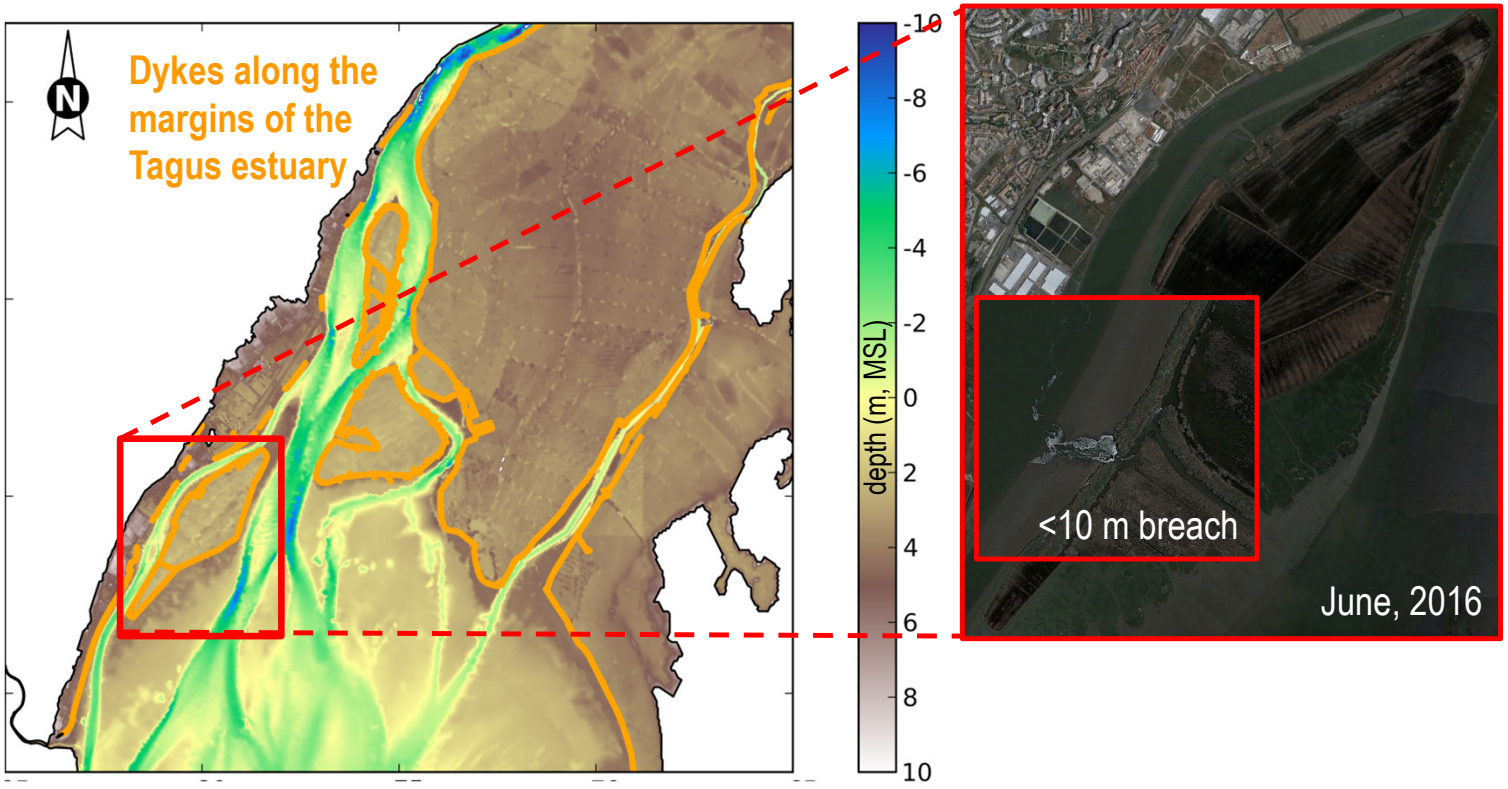
Material damage along the estuarine margins (walls, sidewalks and urban furniture)

Material damage in houses and shops, road cuts (Seixal historic center)

Damage and overtopping of dykes and inundation of agricultural land (Lezíria Grande VFX)

Interruption of the traffic in the North railroad

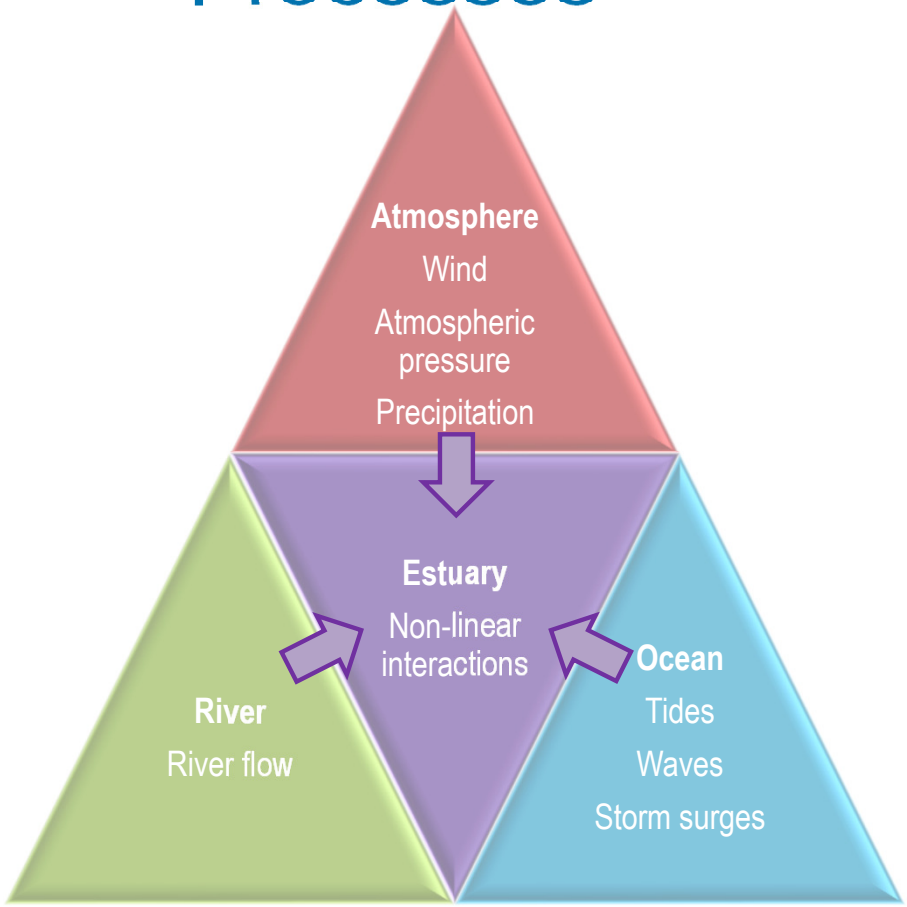
Impacts on the estuary



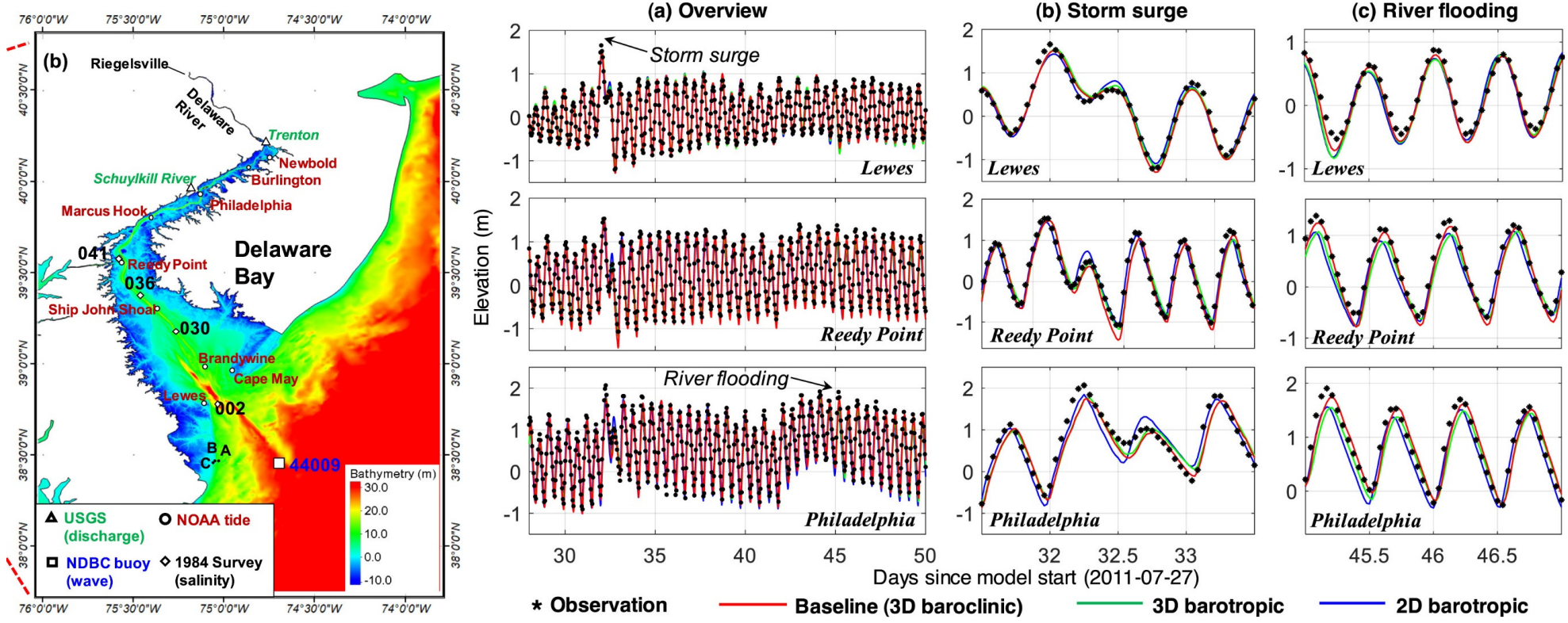
Impacts in the estuary

- Raising all existing sea defenses to keep up with sea level rise may become impossible
- Some inundations may become permanent as the estuary reclaims formerly dry land
- Some estuaries will witness dramatic changes:
  - Increasing salt intrusion
  - Higher tidal prism and inlet deepening
  - Changes in residence times and water quality
- These issues should be anticipated so that timely action is taken

Processes


Atmosphere
Wind
Atmospheric pressure
Precipitation
Estuary
Non-linear interactions
River
River flow
Ocean
Tides
Waves
Storm surges

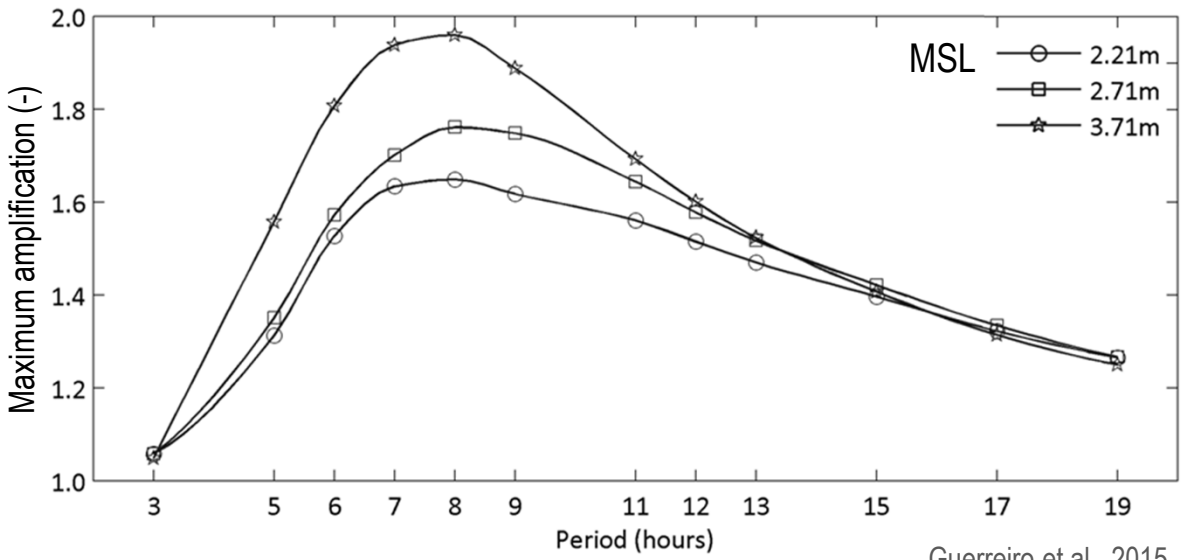
Interaction between river and ocean forcings: importance of baroclinicity on extreme water levels



Ye et al., 2020

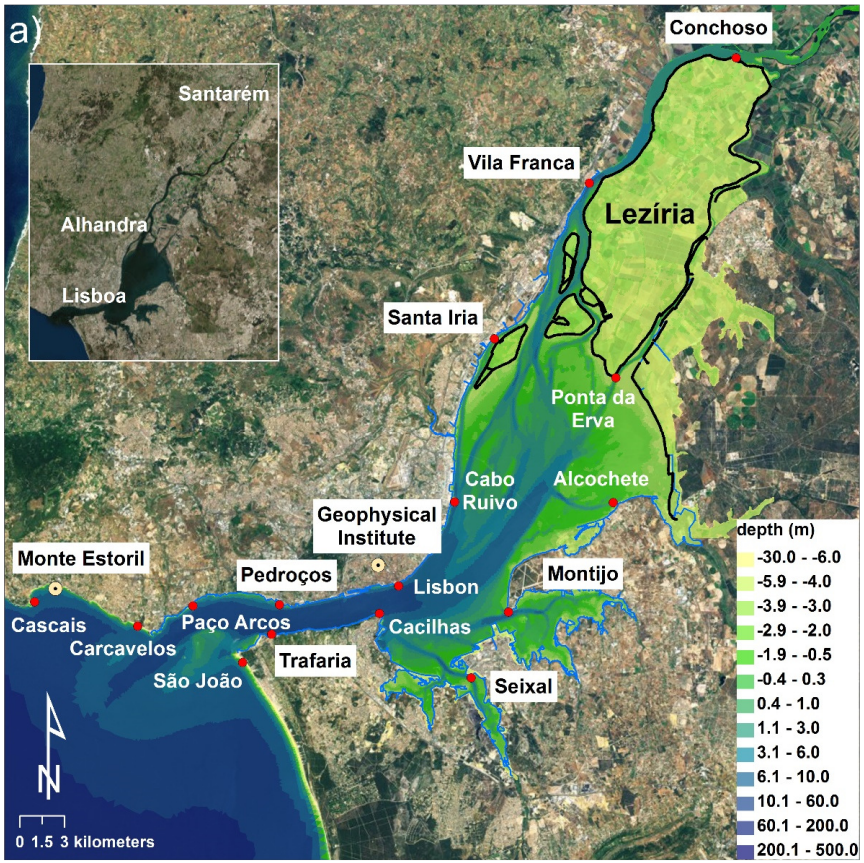
Interaction between MSL and tides: importance of resonance on tidal amplitudes

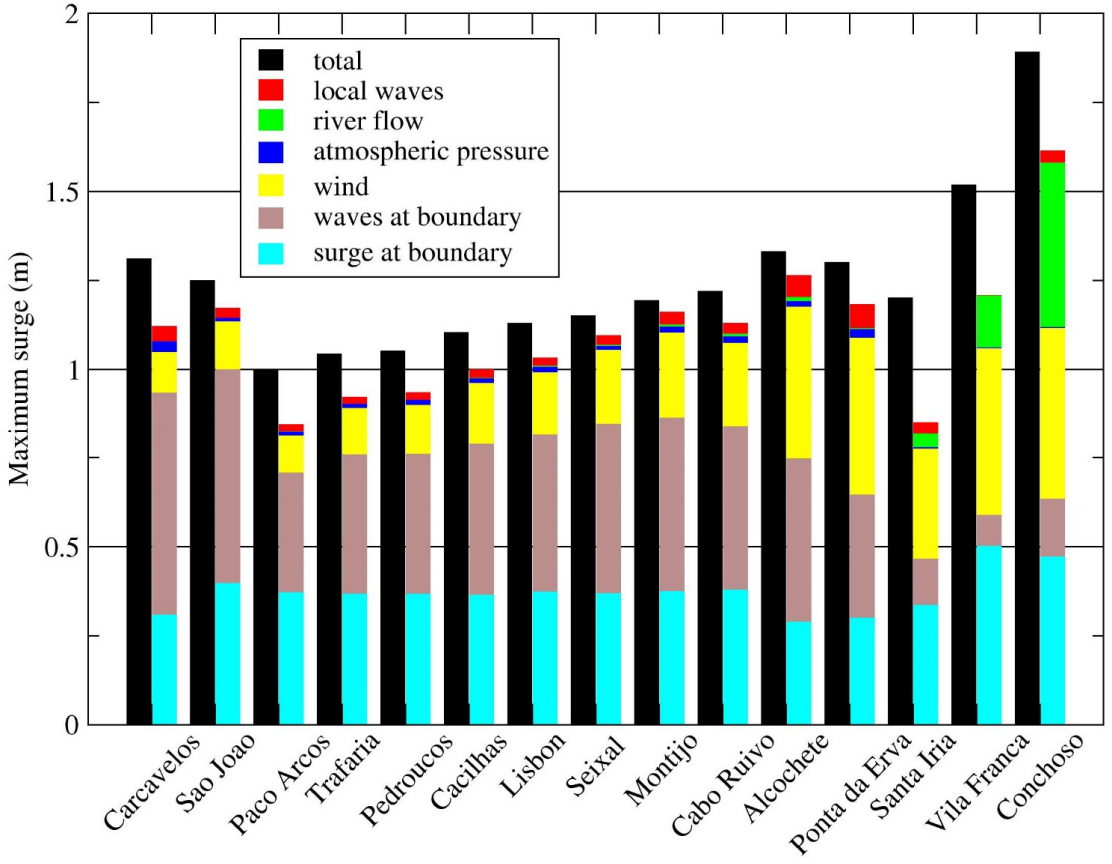
- The Tagus estuary has a resonance period of about 8 hours
- Semi-diurnal tides are amplified by resonance inside the estuary
- SLR will increase the amplification of semi-diurnal tides by resonance
- Hence, the effect of SLR on extreme water levels will be higher than a linear approach would suggest



Guerreiro et al., 2015

Dominant processes in the Tagus estuary

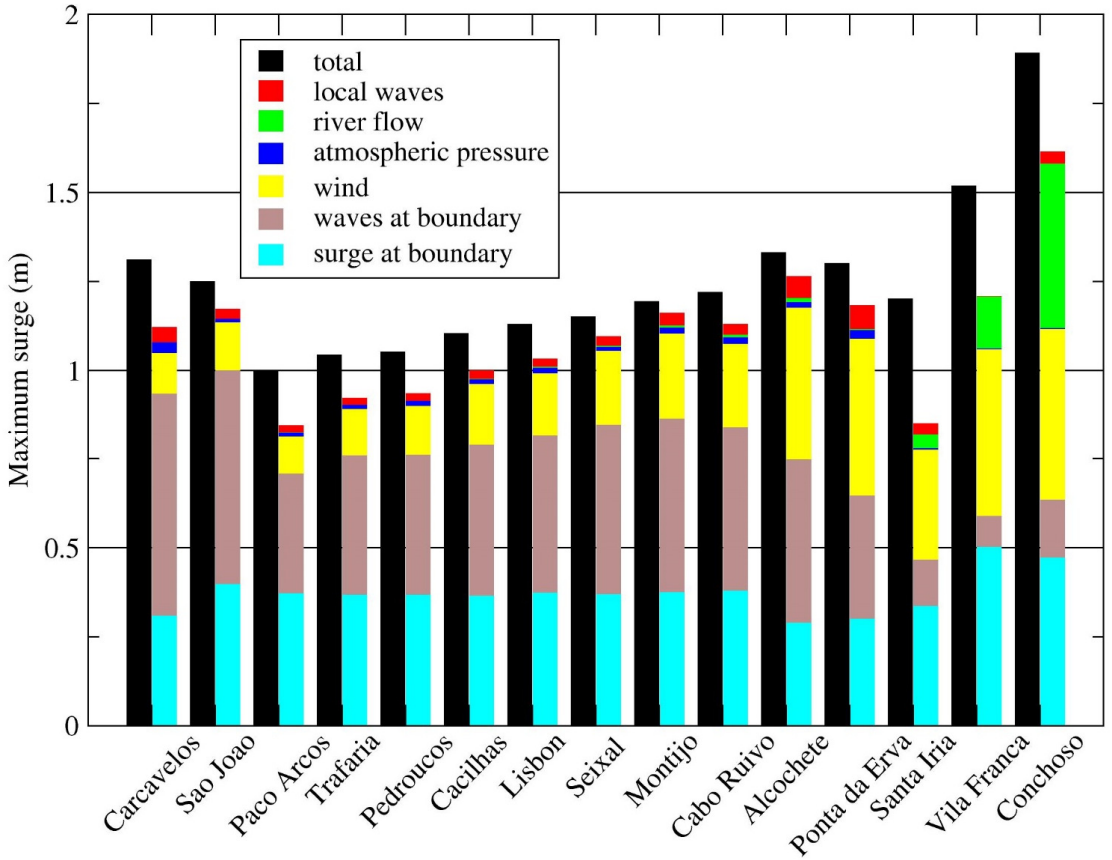




Fortunato et al., 2017

Dominant processes in the Tagus estuary

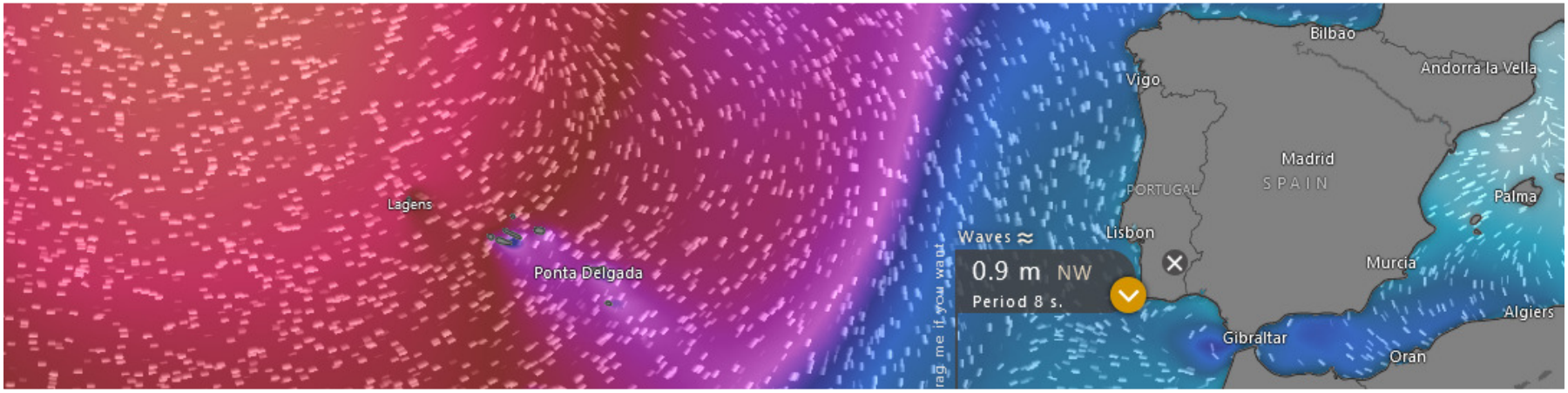
- The ocean surge plays an important role and propagates far into the river
- The (ocean) wave setup also plays an important role and affects the whole estuary
- Local winds are important in shallow regions
- The effect of the river flow is restricted to the narrow portion of the estuary
- The effect of local waves is negligible
- Portuguese legislation (Portaria 336/2019) should be reviewed



Fortunato et al., 2017

Large-scale predictions

- Global and regional forecasts of ocean dynamics are routinely produced by national and supra-national organizations (NOAA, ECMWF, IPMA, etc.)
- Large-scale accurate forecasts of waves, tides, or surges are produced a few days in advance and are used for civil protection, harbor operation, etc.
- Copernicus forecasts peak water levels in European coasts with a 10% underprediction (Apecechea et al., 2023)



Waves from www.windy.com

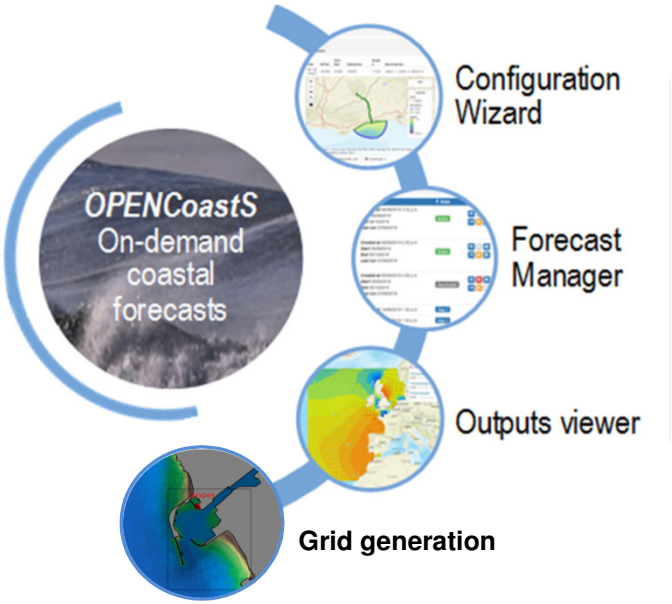
Predictions at estuarine scales

- National and supra-national products are often unsuited for the small estuarine scales and inundation
- Small-scale predictions have more stringent requirements:
  - More complex physical processes (e.g., wave-current interactions, wetting and drying)
  - Small-scale data (e.g., bathymetry), usually unavailable in public repositories
  - Higher and spatially varying grid spacing, to resolve small spatial features (e.g., dykes, narrow channels)
  - Output requirements vary widely with the end-users

⇨ Need for decentralized forecast systems to address local scales

OPENCoastS: on-demand generation of estuarine and coastal forecast systems

- Web portal to assemble on-demand coastal forecast systems for selected coastal areas
- Generates daily forecasts of water levels, wave parameters, 2D and 3D velocities, and 3D salinities, temperatures and water quality variables over the region of interest for 48 hours
- Based on numerical simulations of all relevant physical processes
- Services to deploy, manage, and visualize and download results
- Generation of 2D unstructured grids and vertical meshes

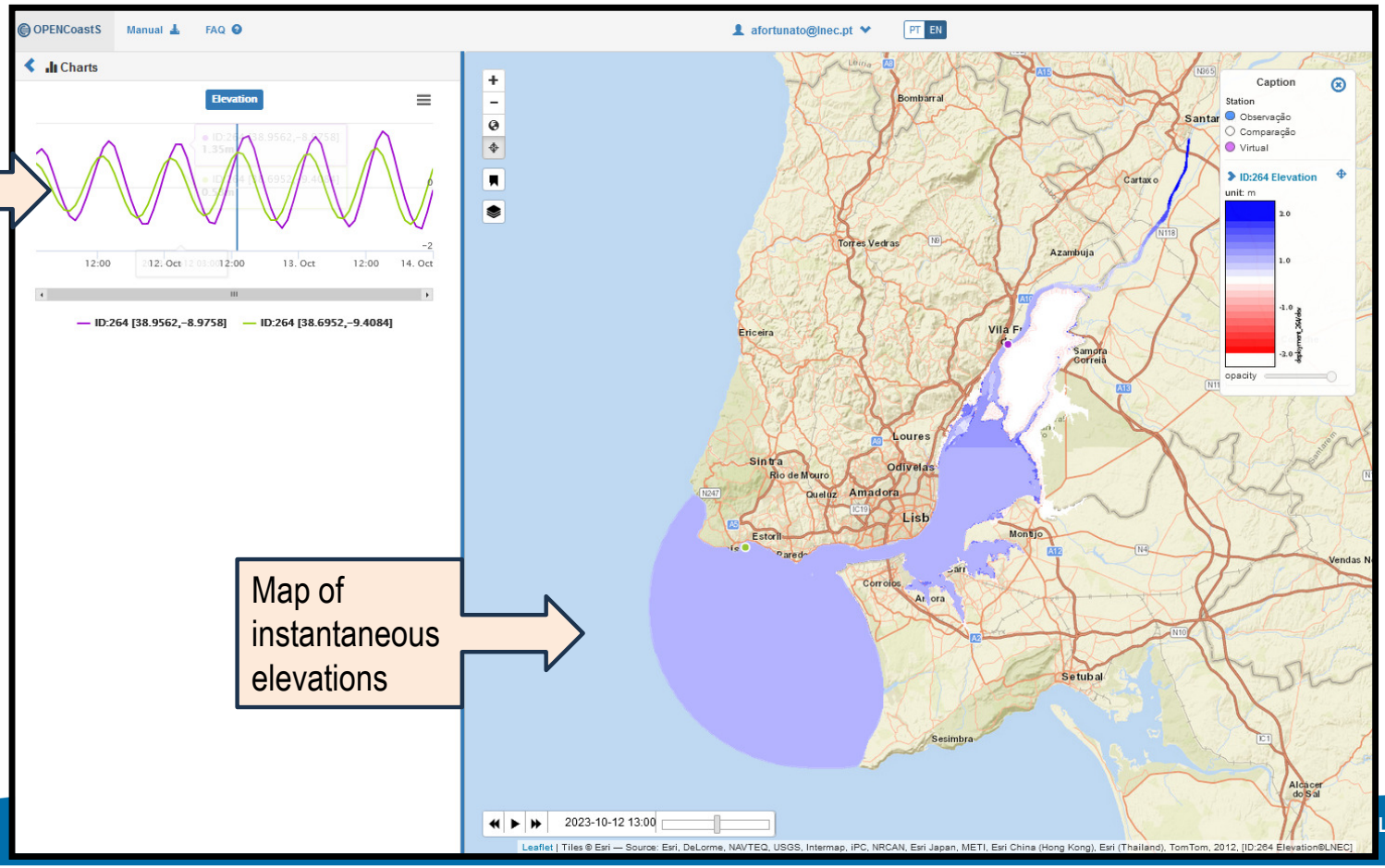


OPENCoastS

https://opencoasts.ncg.ingrid.pt; Oliveira et al., 2020, 2021

Example: 2D forecast system for the Tagus estuary in OPENCoastS

Time series of water levels at Cascais and Vila Franca de Xira



Map of instantaneous elevations

Take-home messages

- The problem
  - Estuarine margins are vulnerable because many large cities grow around estuaries
  - The hazard will keep on increasing due to climate change
  - Many estuaries will experience dramatic change associated to sea level rise
- The processes
  - Estuarine water levels are determined by fluvial, ocean and atmospheric processes
  - The interactions between these forcings can be non-linear
  - Portuguese legislation does not take all the main drivers into account
- The predictions
  - Large-scale ocean forecasts are now routinely produced by national and supra-national organizations, but small-scale (estuarine) forecasts should be performed by local institutions
  - OPENCoastS empowers users to generate their own forecast systems and provide a key component of Digital Twins
  - Simplifying the generation of forecasts paves the way to ensemble predictions, which will improve accuracy

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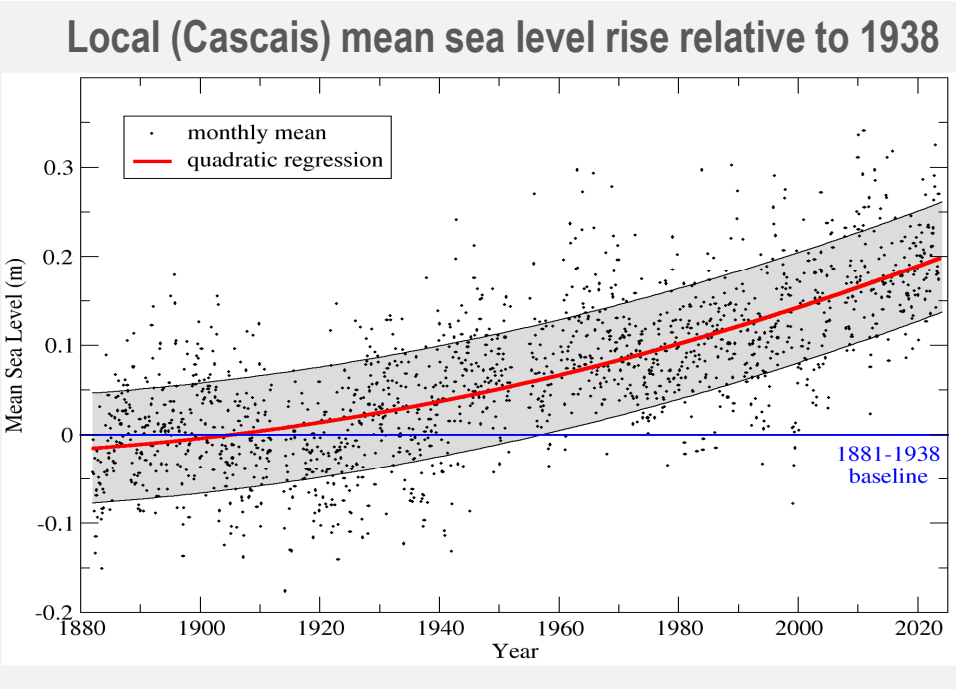
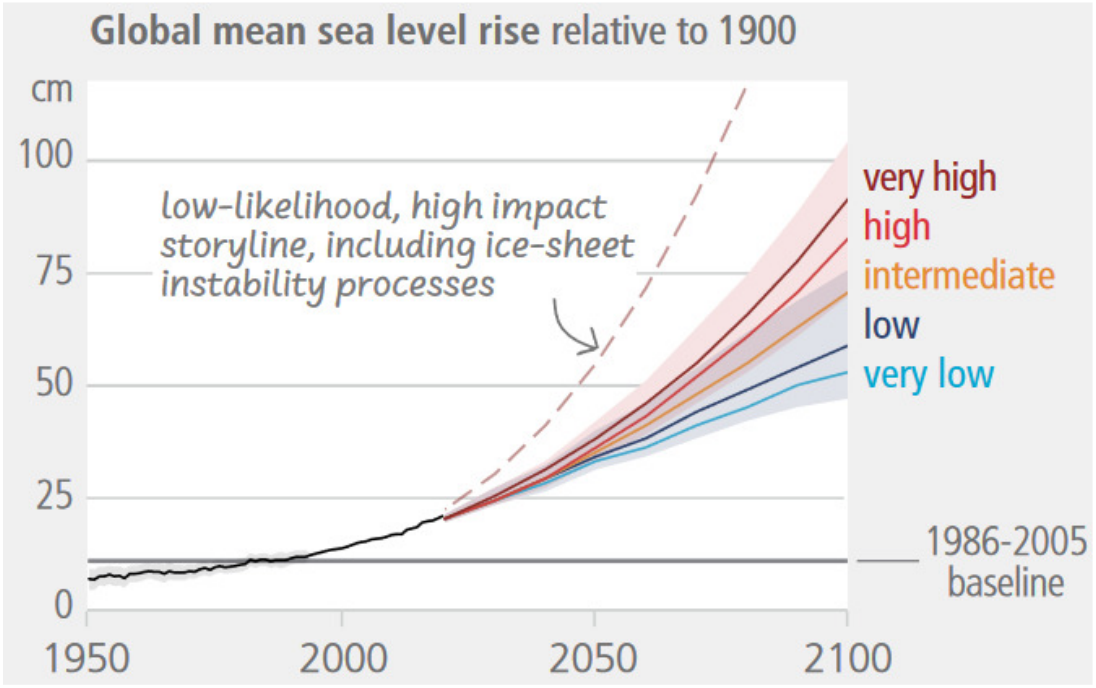
Sea level rise



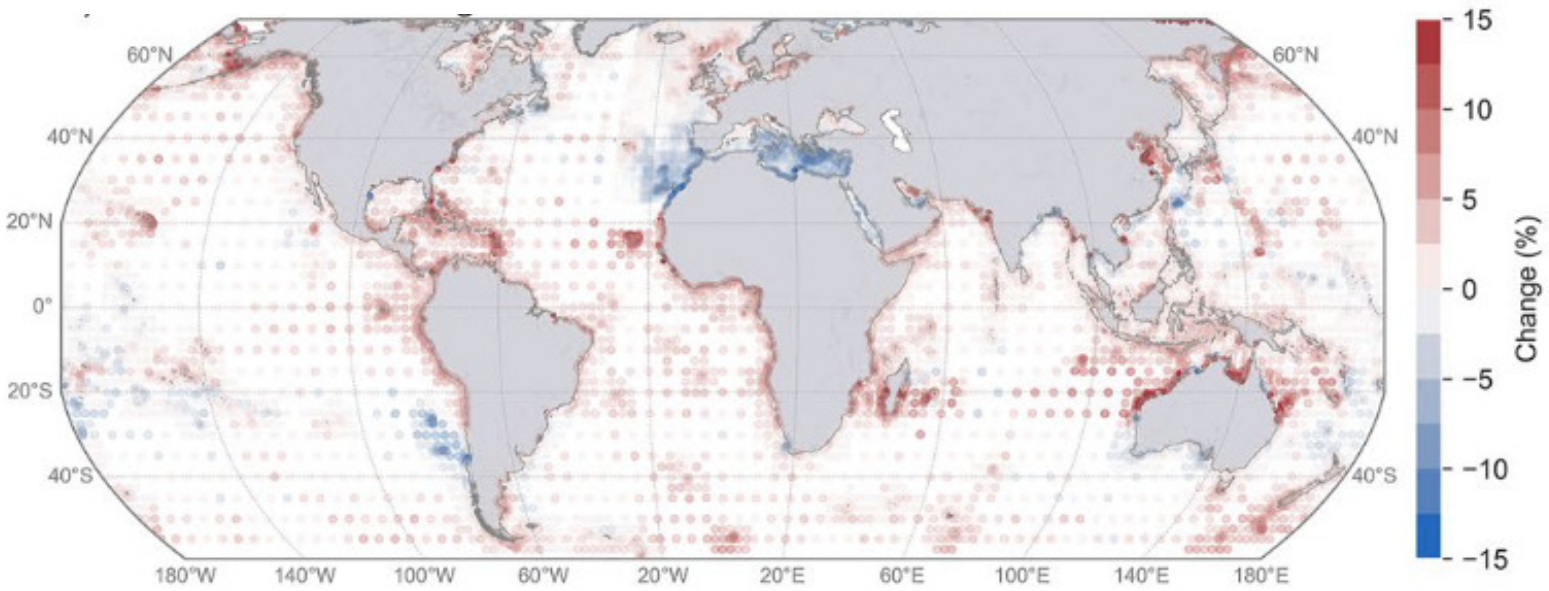
Past: Cascais tide gauge 1881-2023



Future: IPCC projections 2023

Fortunato et al., 2023

Changes in storminess (extreme storm surge level)



Relative change in the extreme storm level with a 10-year return period between 2021-2050 and 1951-1980

Muis et al., 2023