ADVANCES IN COASTAL FLOOD MODELLING WITH LISFLOOD-FP : INTEGRATING WAVES DYNAMICS AND TEMPORARY DUNES

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Introduction

- **Accurate modelling** and **effective management** of coastal flood events are **critically important** for **risk prevention**

- Modelling challenges:
  - Observational flood maps
  - Accurate topographic data
  - Reliable boundary conditions
- Local challenges:
  - Seasonal defences

- Improvements:
  - Seasonal defenses representation
  - Better parameterization of waves (including the swash)

Model approach

- LISFLOOD-FP (Shaw et al., 2021) model known flood events in Italy for which flood maps exist.

- LISFLOOD-FP inputs:
  - Topographic data → Digital Terrain Models (DTMs)
  - Coastline → Boundary condition points
  - Boundary information → Total Water Level (TWL)

LISFLOOD-FP's boundary conditions

- Waves contribute in a complex way to Total Water Levels (TWL).
  - The Setup contributes as a continuous mean coastal sea level.
  - The Swash in two different ways:
    - 1) A major driver of erosion, possibly contributing to the collapse of coastal defenses like sandy dunes.
    - 2) Intermittent water supply for coastal inundation.

- Improve the TWL parametrization in LISFLOOD-FP by introducing a swash boundary condition (Stockdon et al., 2006).

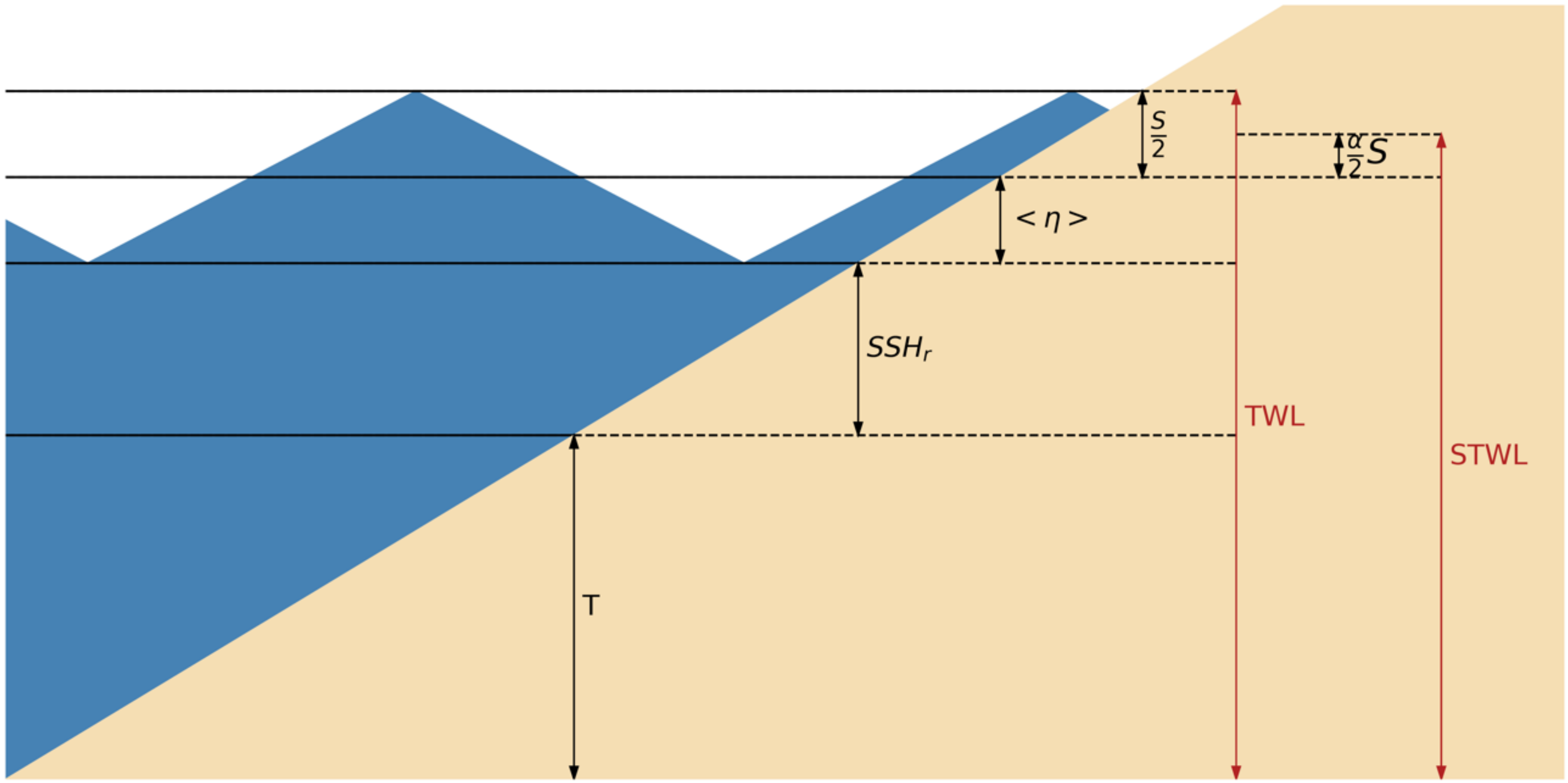


Figure 1 – Schematics of the ocean components for the water level and the water supply associated with the swash where T is the tide component, SSH_r is the Sea Surface Height residuals, <n> is the wave setup, S is the swash, α is the overwash efficiency, TWL is the Total Water Level and STWL is the Supply Total Water Level.

Coastal Protection

- The approach consists of adding protective features to the DTM, allowing the model to reproduce their effect in blocking the water flow.
- Each time step: Water Depth (WD) in the neighborhood of the dune compared with its Failure Water Depth (FWD).
- When FWD is exceeded, the dune is entirely removed.

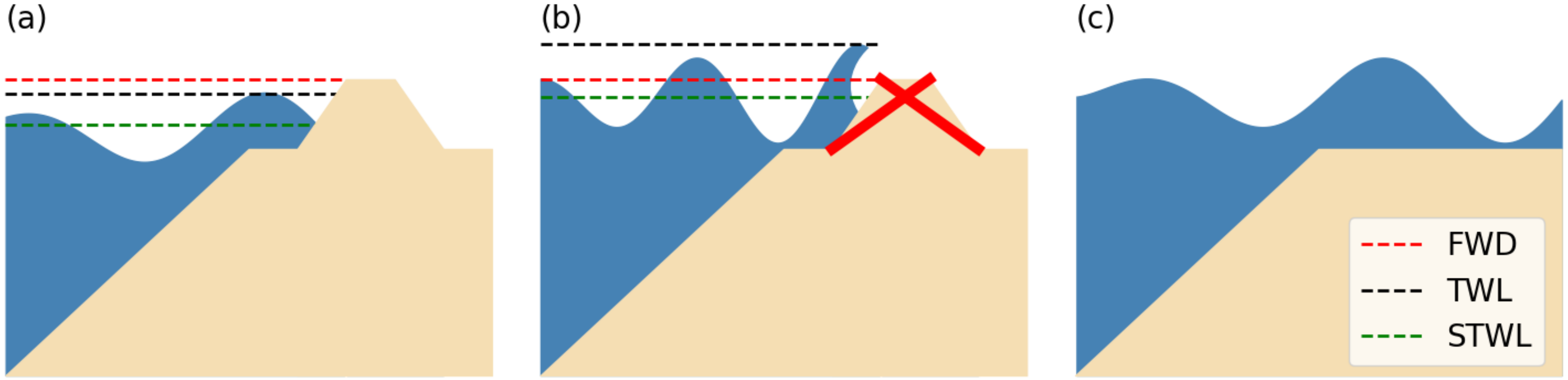


Figure 2 – Schematic representation of coastal protections in LISFLOOD-FP. (a): protective action when Total Water Level (TWL) < Failure Water Depth (FWD). (b): failure for TWL > FWD. (c) free flood propagation upon protection failure.

- For the sides of the dune facing the boundary, the FWD is compared to the full TWL, and not the STWL, as the swash plays a prominent role in dune erosion (e.g. van Rijn, 2009).
- For the simulations in Cesenatico (ER), a FWD of 1.4 meters was assigned to all the dune cells.

Cesenatico's simulations

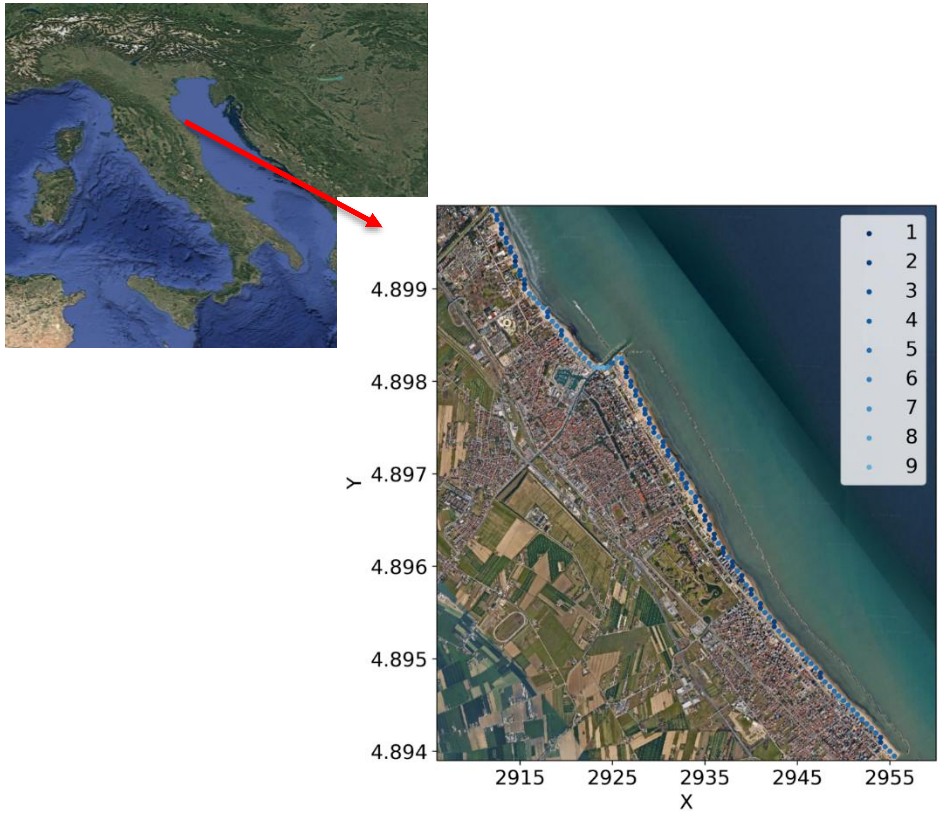
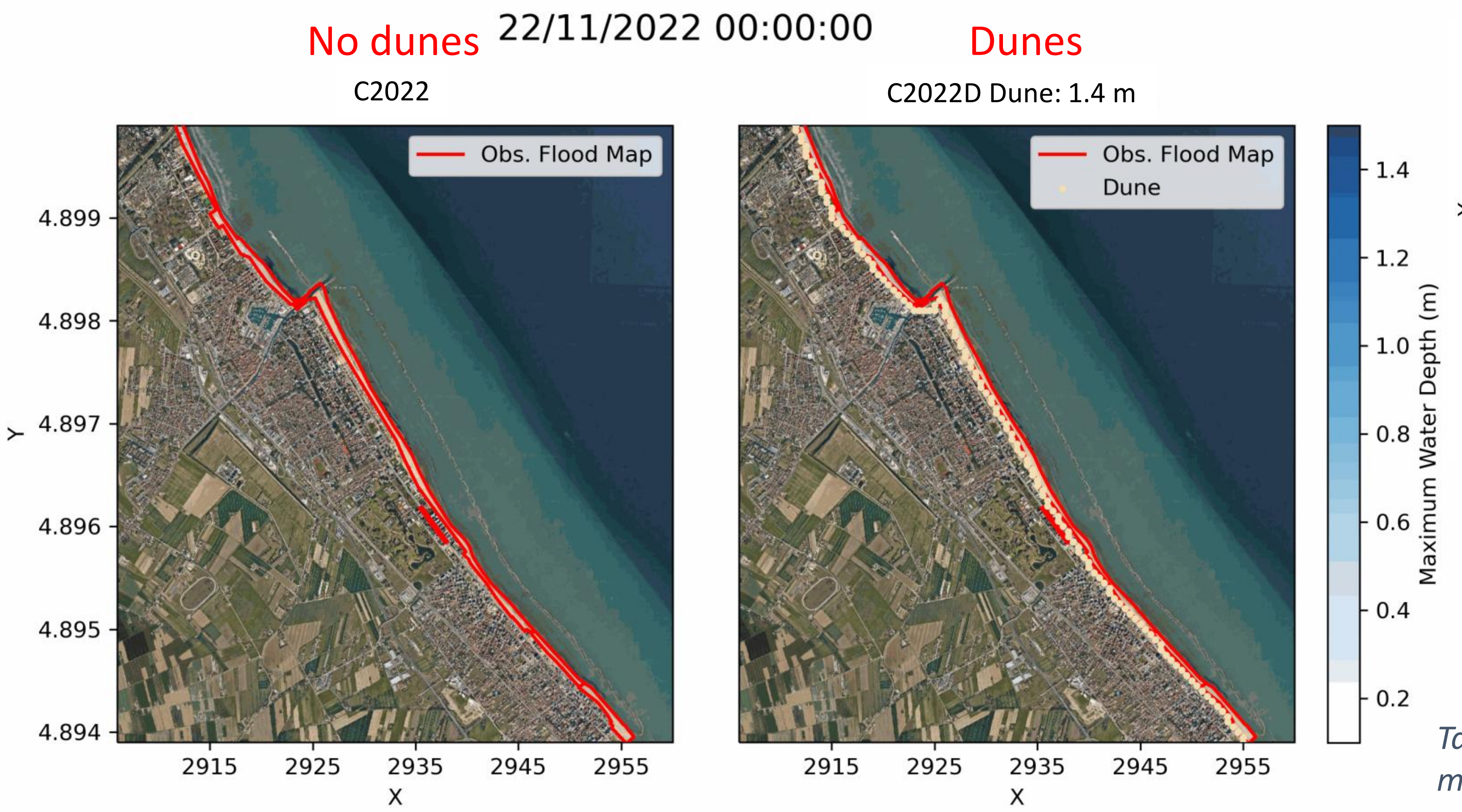


Figure 3 - Different boundary condition points associated with the coastline angle along the Cesenatico area. Darker (lighter) colors represent a more meridional (zonal) orientation of the coast.

- DTM: Regione Emilia-Romagna with 50 m resolution.
- Boundary conditions: Hindcast from Mentaschi et al. (2023)
- Simulations:
  - Agatha storm: 02/02/2015 00:00:00 to 06/02/2015 23:00:00
  - Denise Storm: 22/11/2022 00:00:00 to 23/11/2022 23:00:00
- Simulations with (C2015D and C2022D) and without (C2015 and C2022) dunes.

2022: Save by the dunes!



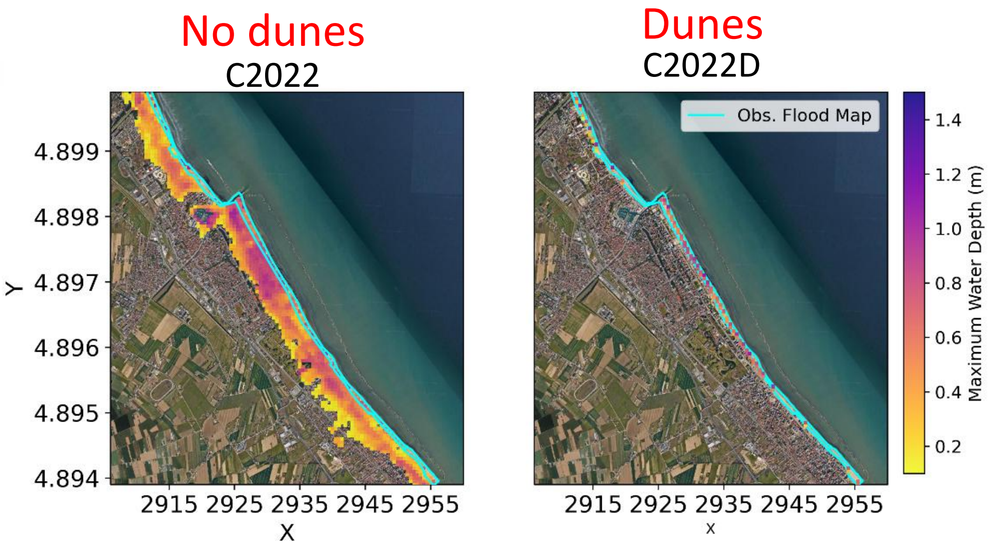
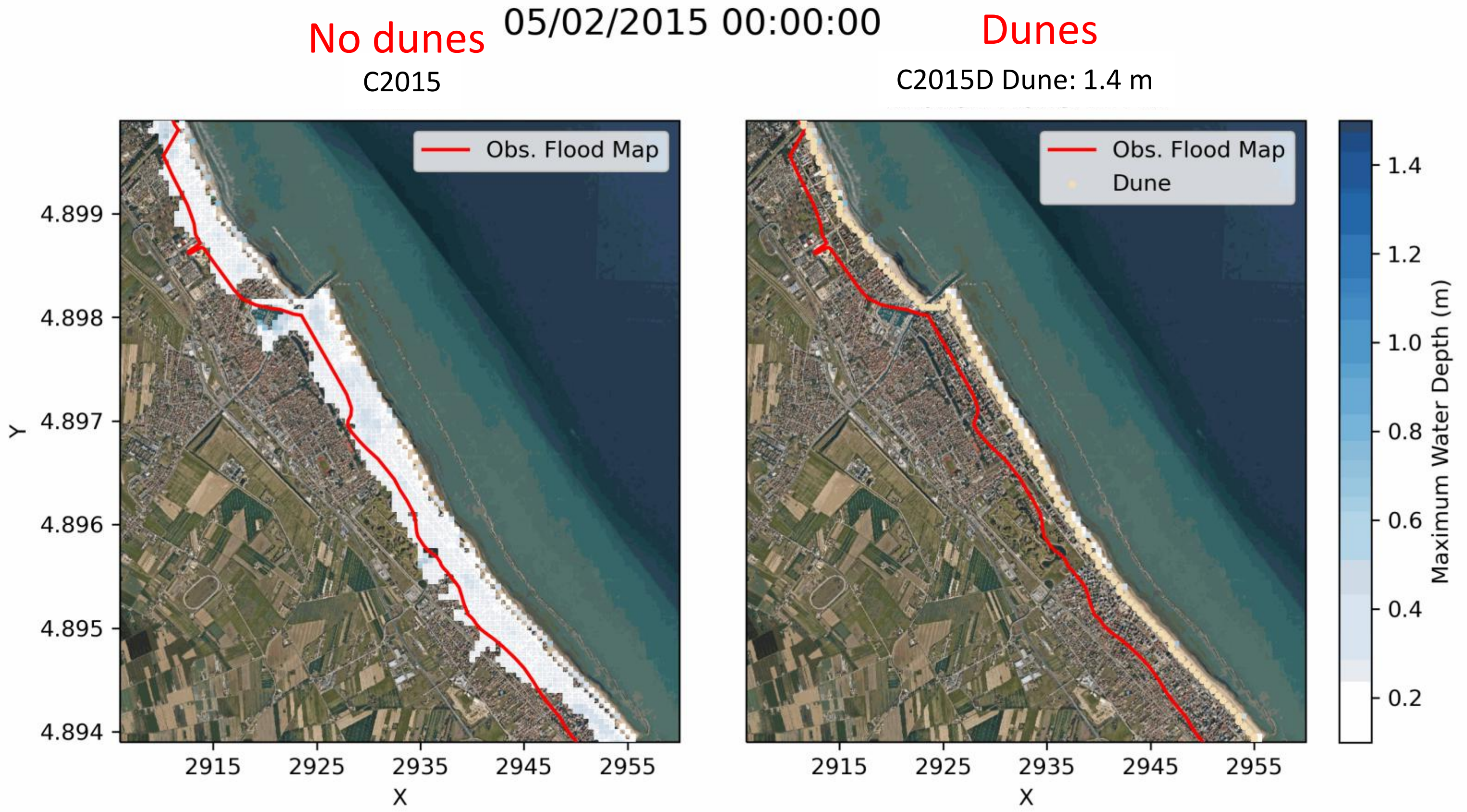


Figure 4 – LISFLOOD-FP maximum water depth (m) for the 2015 Cesenatico simulations without protections C2022 (a) and with protections C2022D (b). The cyan line corresponds to the limits of the observational flood map.

Table 1 – Evaluation metrics for simulations C2022 and C2022D.

Metrics	C2022	C2022D
BIAS (%)	739	72
F (%)	640	5
H (%)	99	67
C (%)	13	64

2015: Some dunes to flood it all!



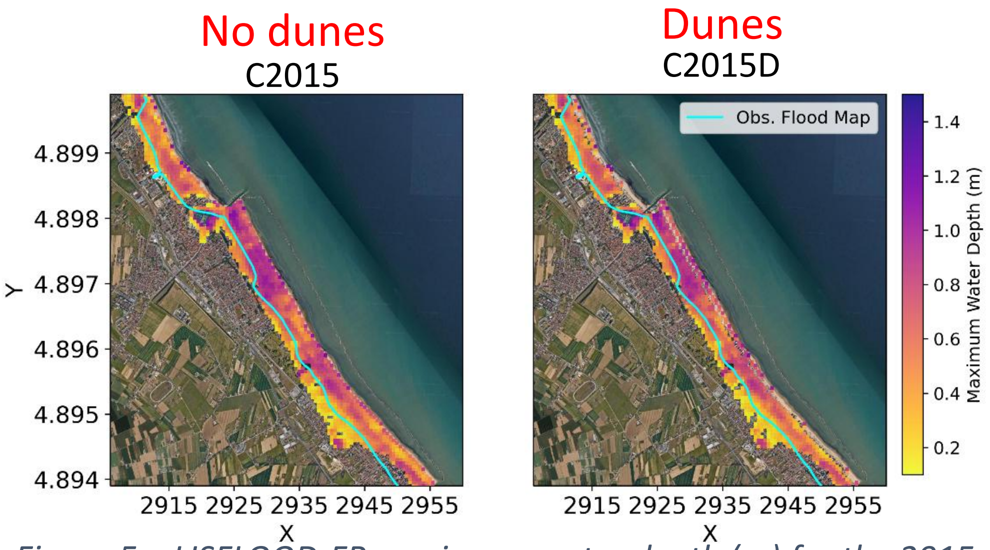


Figure 5 – LISFLOOD-FP maximum water depth (m) for the 2015 Cesenatico simulations without protections C2015 (a) and with protections C2015D (b). The cyan line corresponds to the limits of the observational flood map.

Table 2 – Evaluation metrics for simulations C2015 and C2015D.

Metrics	C2015	C2015D
BIAS (%)	132	130
F (%)	39	43
H (%)	92	86
C (%)	66	60

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Abstract | Discussion | Metrics

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Numerical modelling framework for assessing dune effectiveness against coastal inundation

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Abstract. Coastal inundation is one of the prominent natural hazards threatening both economic assets and human lives. Precise modeling of these events is vital for comprehensive risk assessment, yet there is a persistent gap in data availability and modelling accuracy for coastal flood mapping. In this study, we expanded the LISFLOOD-FP model's ability to simulate coastal floods by incorporating wave setup and swash, as well as the interaction with protective infrastructures like temporary dunes. This improved approach was applied to the coastline of Cesenatico, Italy, where dunes are built each winter as seasonal coastal defenses. We analyzed two storm events for which observational flood maps are available for validation: the 2015 Saint Agatha Storm, which saw intense waves breaching the dunes and causing extensive inland flooding, and the 2022 Denise Storm, when the dunes withstood the storm and successfully shielded the coast. Our results demonstrate that dunes are highly effective in mitigating inundation, particularly during the 2022 event. However, they also reveal that the failure of even a small portion of the dunes can lead to widespread inundation, emphasizing the need for optimized dune design. These findings represent a significant advancement toward developing a digital twin of coastal regions, providing valuable support for a range of coastal management activities.

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Short summary

We improved a computer model to simulate coastal flooding by including temporary barriers like...
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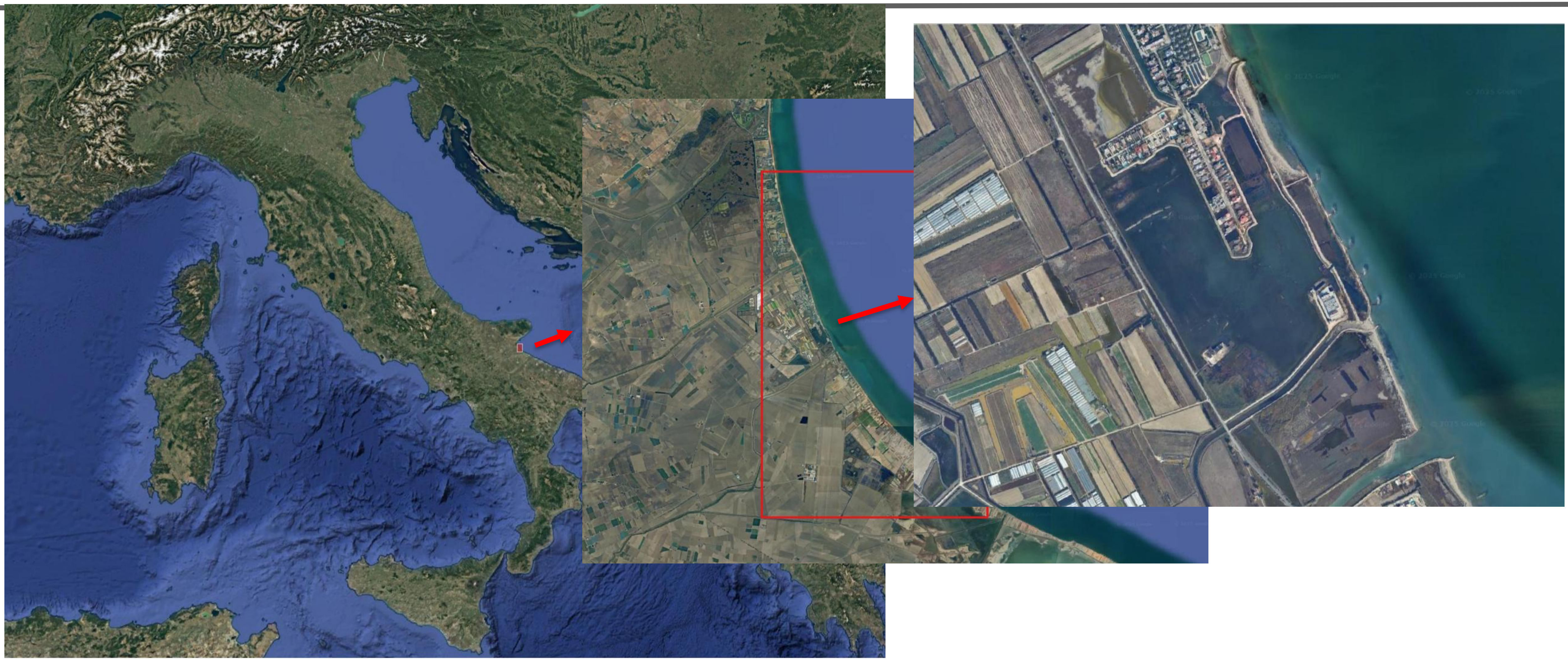
Manfredonia's simulations



Manfredonia's simulations

- DTM: Regione Puglia with 10 m resolution.
- Boundary conditions: SSH from AdriaFs + Waves from Mentaschi et al. (2023)
- Simulations: Nov/2019

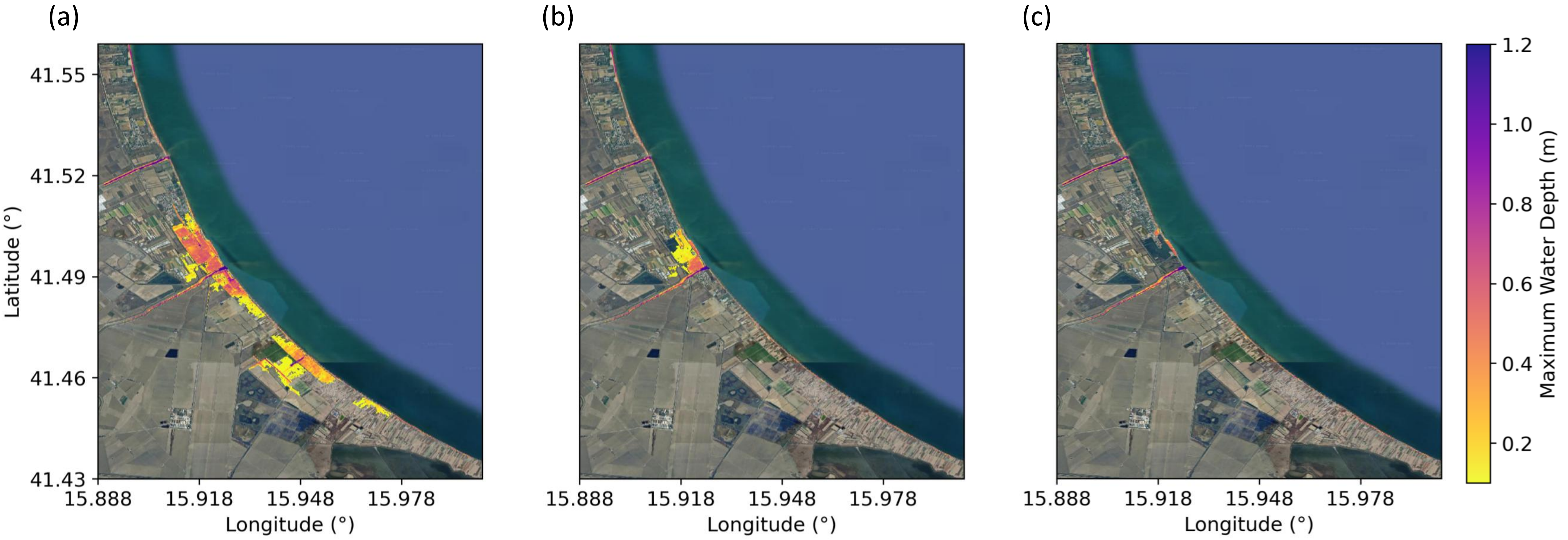


Figure 6 – LISFLOOD-FP maximum water depth (m) for the simulations without protections (a), protection only in the coast (b) and protections in the Ippocampo area (c).

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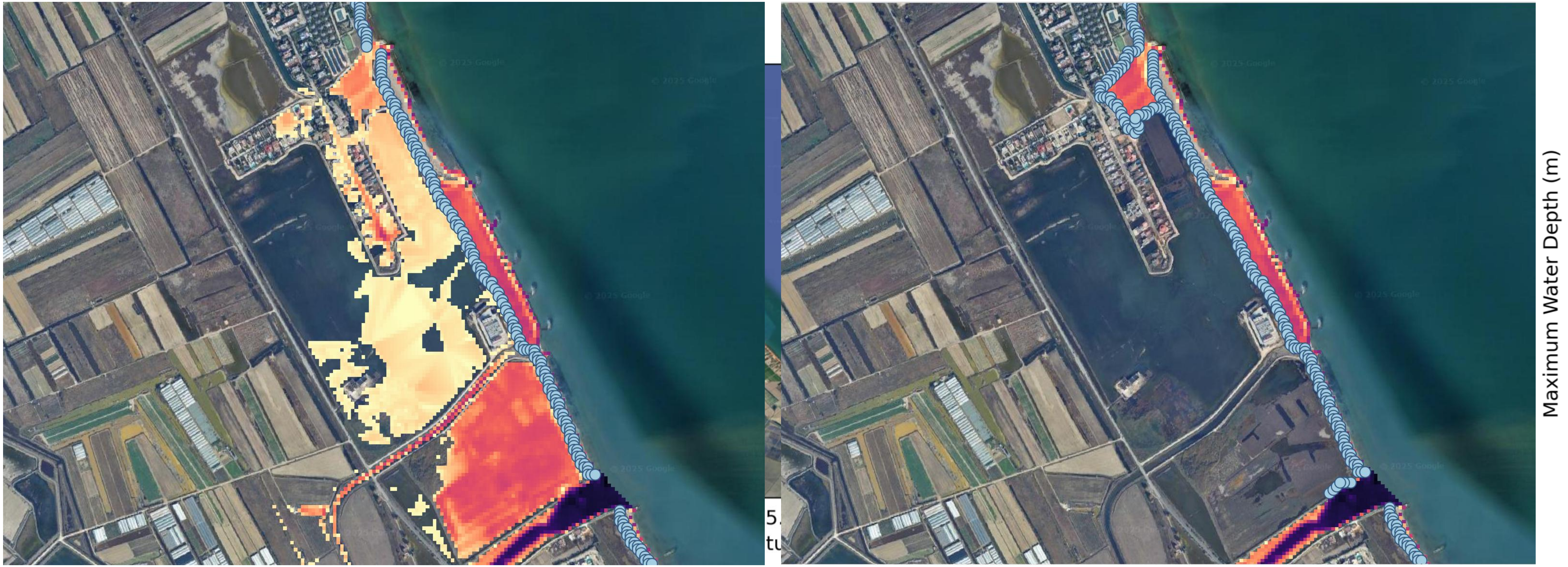

Figure 6 – LISFLOOD-FP maximum water depth (m) for the simulations without protections (a), protection only in the coast (b) and protections in the Ippocampo area (c).

Conclusions

- Importance of wave consideration and representation of coastal defences.
- Significantly improved ability to replicate accurately inundation events.
- Improvement cost: the uncertainty regarding the exact topographic location and size of the temporary dunes propagates non-linearly in the extent of the simulated flood map.
- How to address the issue? Ensemble approach thorough probabilistic assessment of coastal hazards generating simulations with a variety of dune geometries and extreme sea level scenarios. ***The implementation of such a strategy would be facilitated by the model's high computational efficiency.**
- These findings represent a significant leap in the development of a digital twin for our coastal regions.

Thank you!

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