4TH INTERNATIONAL WORKSHOP ON WAVES, STORM SURGES, AND COASTAL HAZARDS
Incorporating the 18th International Waves Workshop

Proof of Concept for an Advanced Real-Time Early Warning System for Coastal Flooding Events at Playa del Sardinero (Santander, Spain)

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Purpose and motivation

Social

The Santander City Council does not have an early warning system that provides information about these events.

Purpose and motivation

Technical / Scientific

There is no technical solution that integrates the relevant physical processes into an efficient forecast system in Sardinero Beach.

What we know so far?

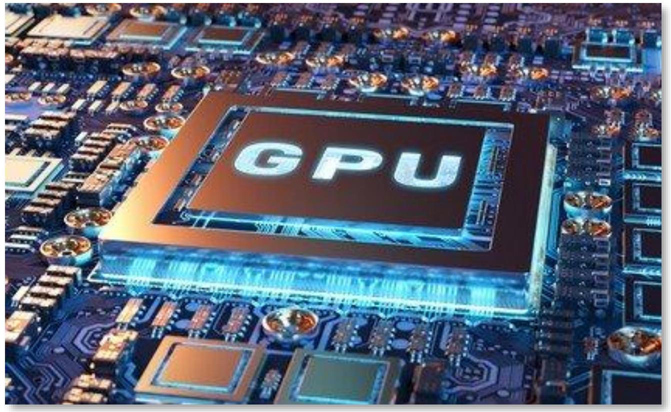
1. Linear/spectral wave models **are very efficient and stable but do not include all processes**.
2. Advanced wave models (*Xbeach-NH, SWASH, Boussnesq*) **do include the relevant processes**, but they are often slow and unstable.
3. The use of metamodeling techniques (clustering strategies, surrogate models, hybrid approaches) has **helped to incorporate advanced models** into forecasting strategies.
4. These strategies continue to **consider the hourly sea-state conditions** as part of their general framework.
5. Wave overtopping and flooding events are **strongly controlled by wave forcing and infragravity wave dynamics (and tides)**, which display pronounced spatial maxima and minima varying over both **sub-hourly and super-hourly time scales**.

Objective

To develop a predictive system for coastal overtopping and flooding events, based on an **advanced model** that integrates the **relevant physics** and accounts for **fine-scale processes** (waves) occurring at **sub-hourly time scales** and **persisting** processes (infragravity waves), at **super-hourly scales,** both **concomitant** to tidal oscillations**.**

CELERIS WEB

https://plynett.github.io/



Change the approach from an hourly time-step analysis to an event-based analysis covering 72-hour storm periods

BUT **Is it possible to simulate 72 hours with a Boussinesq model, wave by wave, while changing the instantaneous sea level?**

Experiment 01 – "DRAINING THE POOL"

It consists of reproducing the wave conditions associated with the March 2014 event, but starting to lower (in real time) the sea level with an (unrealistic) draining rate of **x10** times (the real tidal window).

The purpose is to evaluate the stability of the numerical model by analyzing the storm wave response to dynamic sea-level changes, as well as the way shoaling, wave breaking, and beach run-up dynamically adapt to rapid variations in water level.

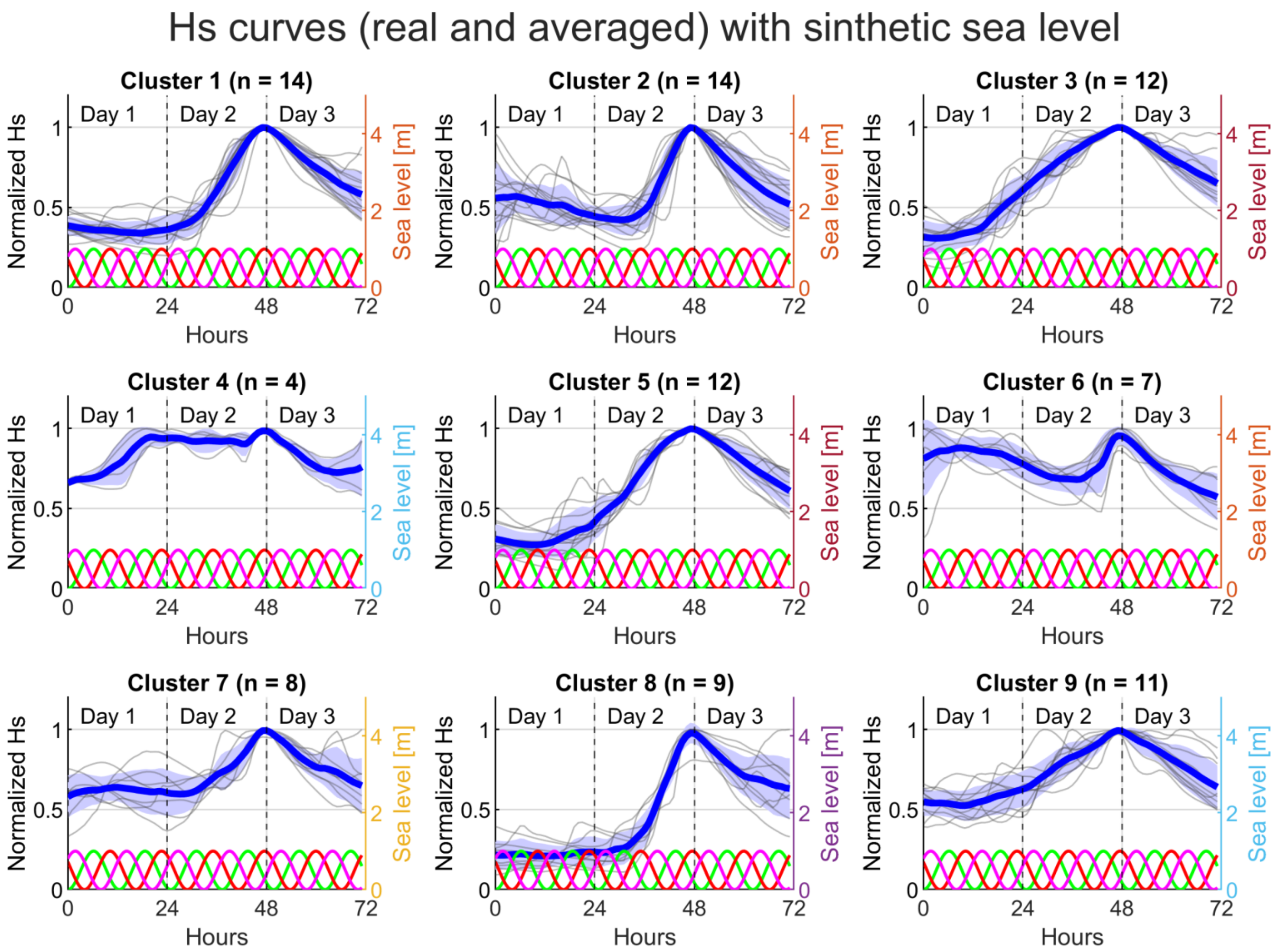
This experiment is essential to subject the model to a stress and stability test and to demonstrate the importance of accounting for the combined physics of wave dynamics, sea level, surf-beat, infragravity waves, and related processes.

Method

A. Based on a 30-year hindcast wave database in the outer zone of the "Sardinero beach", a PCA + k-means clustering was developed for identify similar-shaped storm events.

**The 72-hours storm is identified when the peak of the storm (hourly Hs) are exactly 48 hours from the initial 0 hour (only for those storms with Hs peak>5 m, based into a numerical-based-sensibility-analysis / pre-assessment for those storms that can create flooding events).*

B. A total of 91 storms were isolated (grey lines), averaged and normalized (blue lines) into **K=9 clusters** with a total storm event duration of 72 hours.



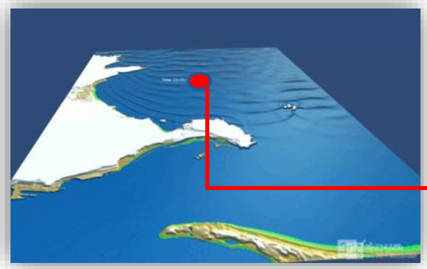
Method

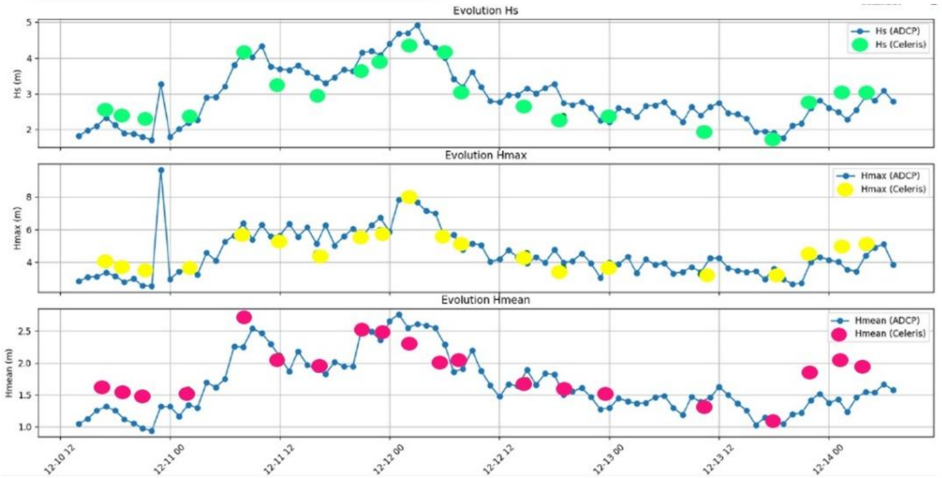
C Each K event were related with **3 possible tide-phase concordance with the 72 hour instantaneous sea level** (-3, +0, and +3 hour shift). To take into account different possibilities within the sea-level evolution, wave breaking, peak of the storm etc.

D A total of K=9 x 3 Hs values x 2 tide levels and x 3 tide phases were created **M=162 cases in total**. Each K case were de-normalized with each individual Hs value proposed (considering peak period Tp and wave direction as the averaged value of each K-storm type. To reduce the catalogue, *as a first approach*).

E Each **M cases were pre-executed with** the (already validated for waves and for the overtopping & flooding event of **March 2014**) CELERIS-WEB numerical model, running **(for the first time in the state-of-the-art!)** the complete 72-hour individual wave evolution simultaneously changing instantaneous sea level (every 2 minutes).

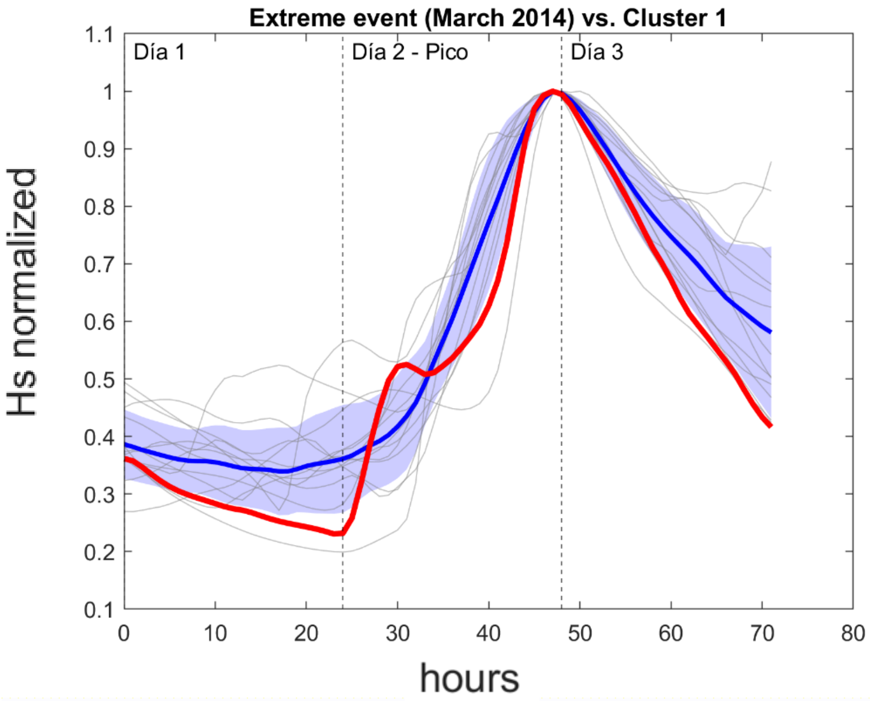
IMPORTANT

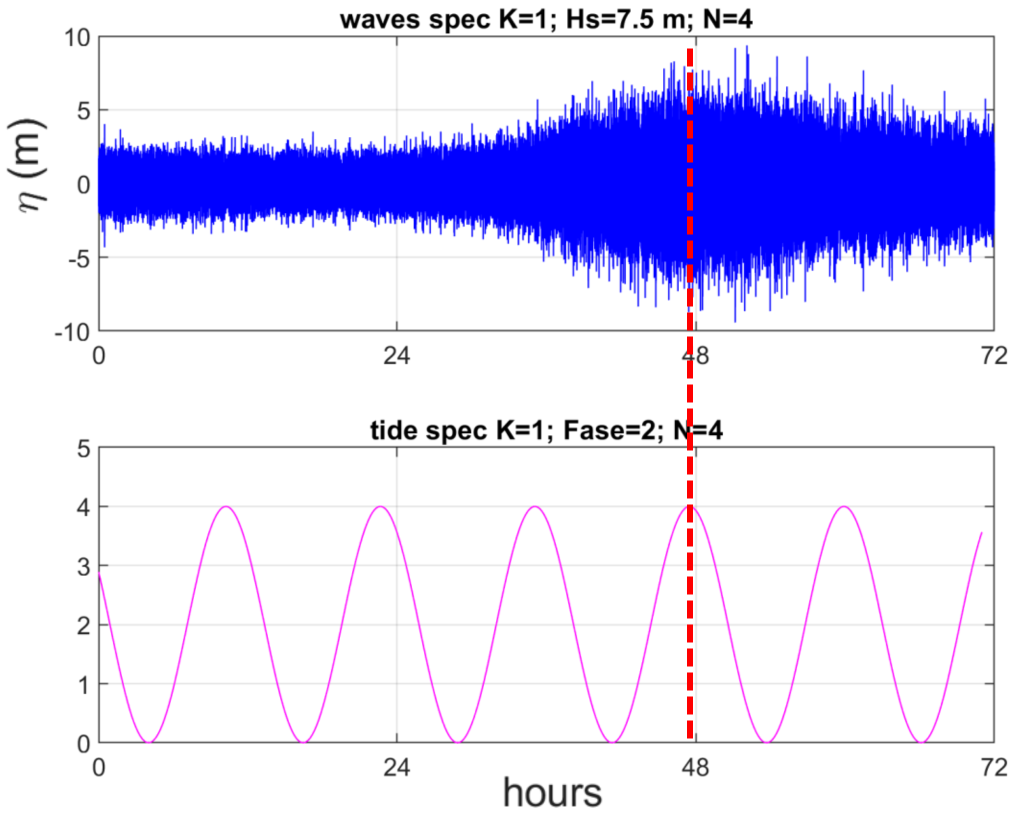


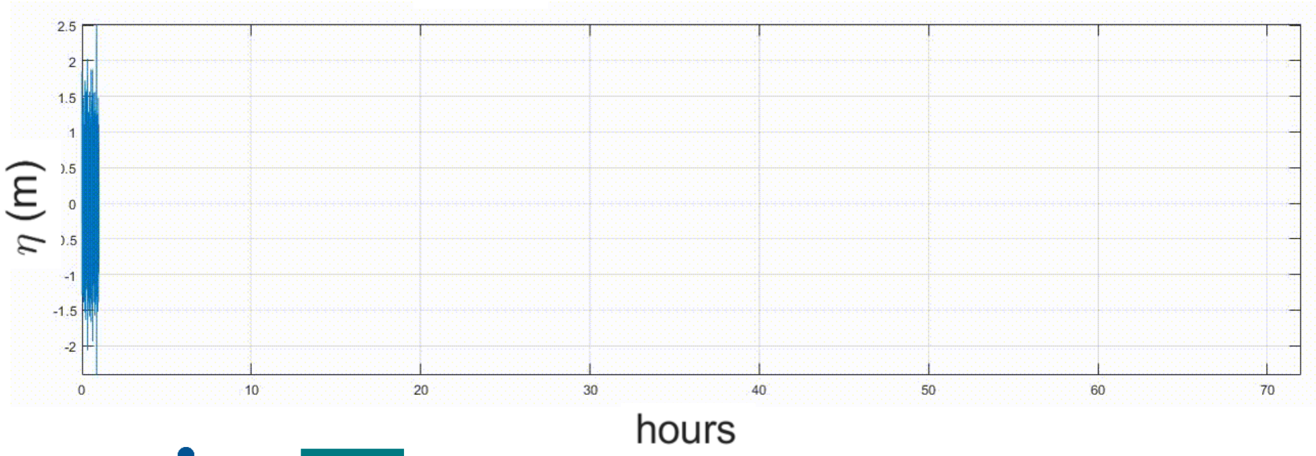


*All **relevant physical processes are solved**, including the natural generation of **infragravity oscillations and surf-beat**. Pre-warming procedures and waiting for the model to reach dynamic equilibrium **are avoided**. Wave propagation **reacts to changes in the instantaneous sea level**. The **overtopping and flooding processes are automatically resolved** (takes only 4 to 6 hour! In a ~1k€ GPU).*

Method







- ✓ *More than **22,000** individual waves.*
- ✓ *More than **390,000** (FFT) harmonics [amplitudes, periods, directions and random phases].*

Experiment – "MARCH 2014 event"

Consists of reproducing the full sea state associated with the 2014 event peak, incorporating the real tidal oscillation. **The animation begins shortly before the tide reaches its maximum level**

The objective is to visualize how the tidal peak approaches and how the waves progressively reach the promenade, realistically overtopping and flooding it (in comparison with observations). At the end of the video, the tide begins to fall, deactivating or reducing the wave overtopping events.

This experiment demonstrates that, within an hourly sea state, there may be a critical sub-window when the tidal peak coincides with the largest waves. Likewise, the largest waves can be deactivated in terms of overtopping due to breaking processes as the sea level drops.

Results

F For each M case, free surface (**TWL**), wave overtopping discharge (q) and fluid velocity (U) were postprocessed and statistically analysed within the 72-hour time series, creating M summary tables and M flooding maps.

Pont 1 – al "El Chiqui" roundabout

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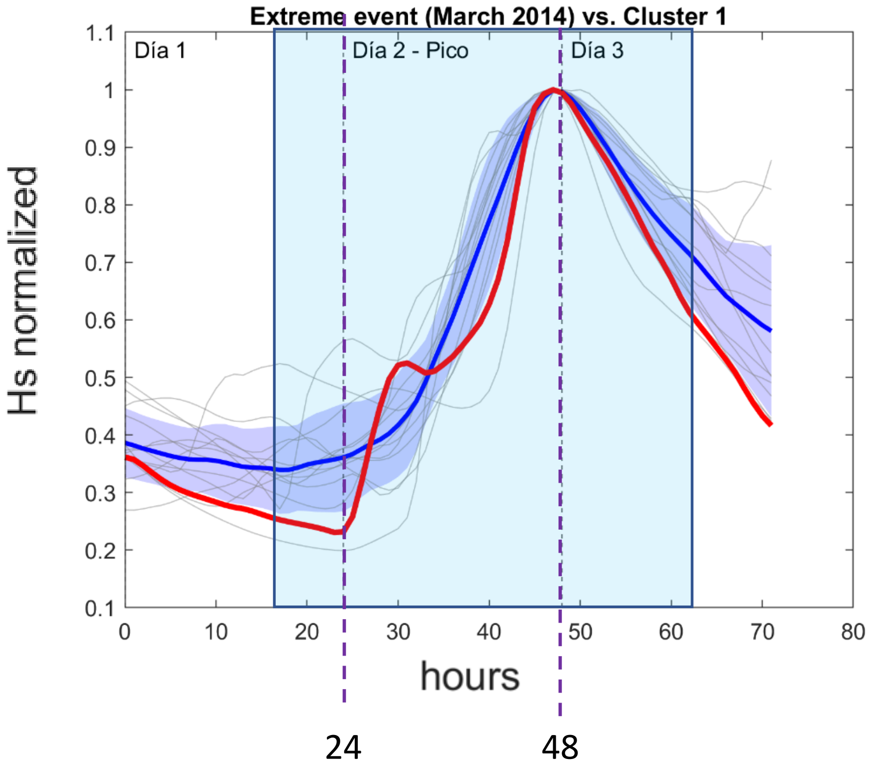
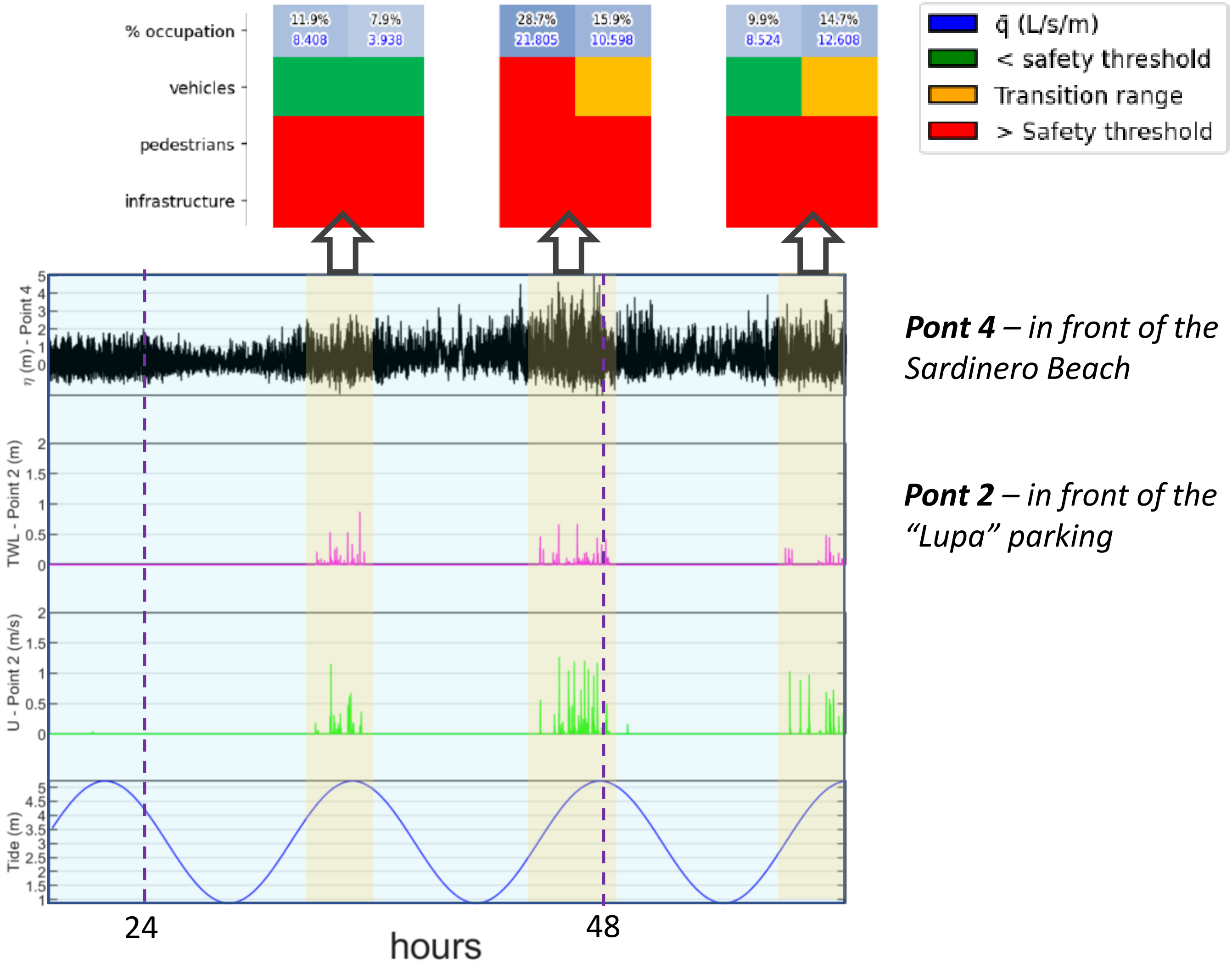
Pont 2 – in front of the "Lupa" parking

Results

It appears that the most significant overtopping and flooding events occur -some- hours before the peak of the storm and the peak of the tide, and they dissipate very quickly after the tidal peak is reached





Pont 4 *– in front of the Sardinero Beach*

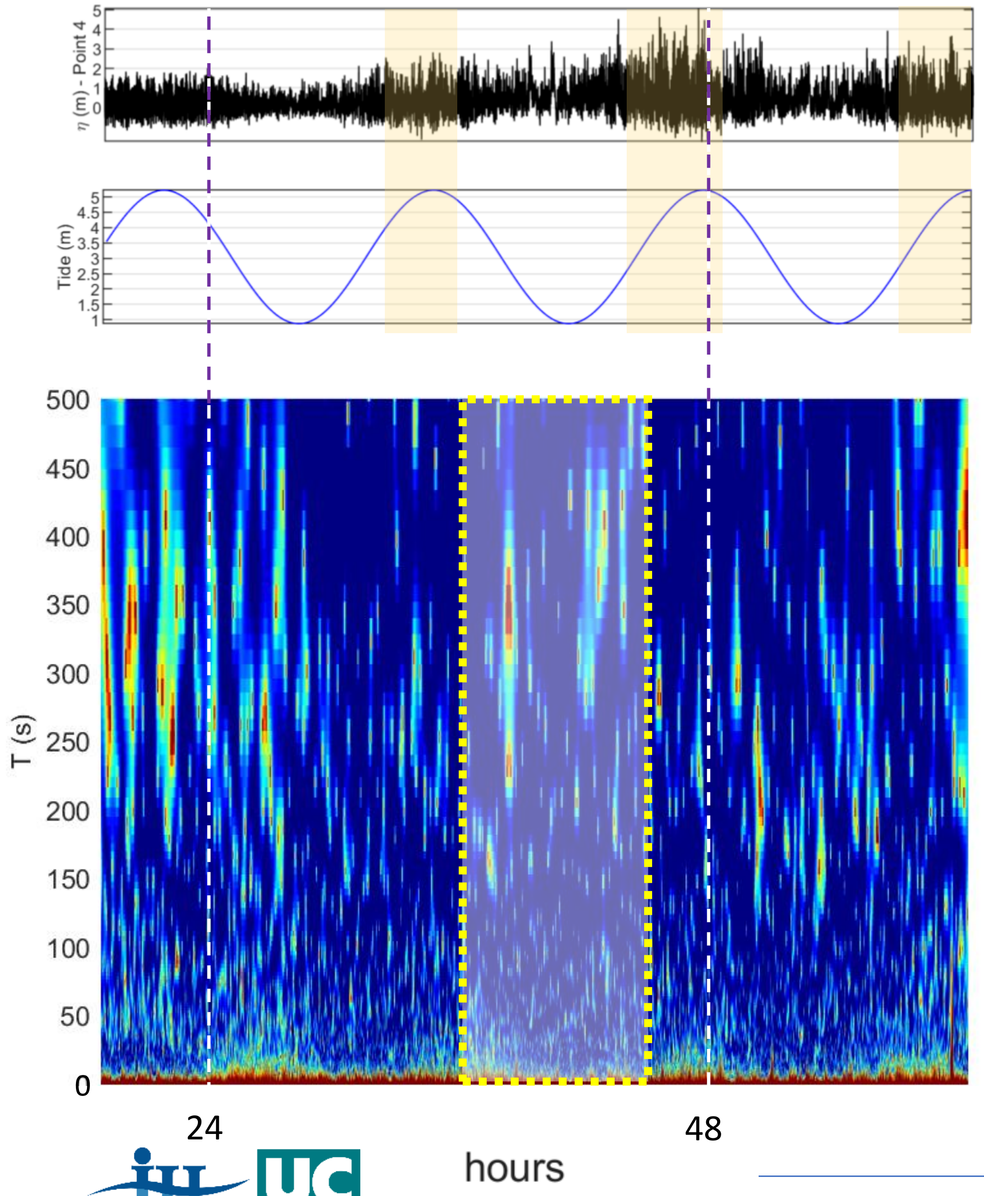
Pont 2 *– in front of the “Lupa” parking*

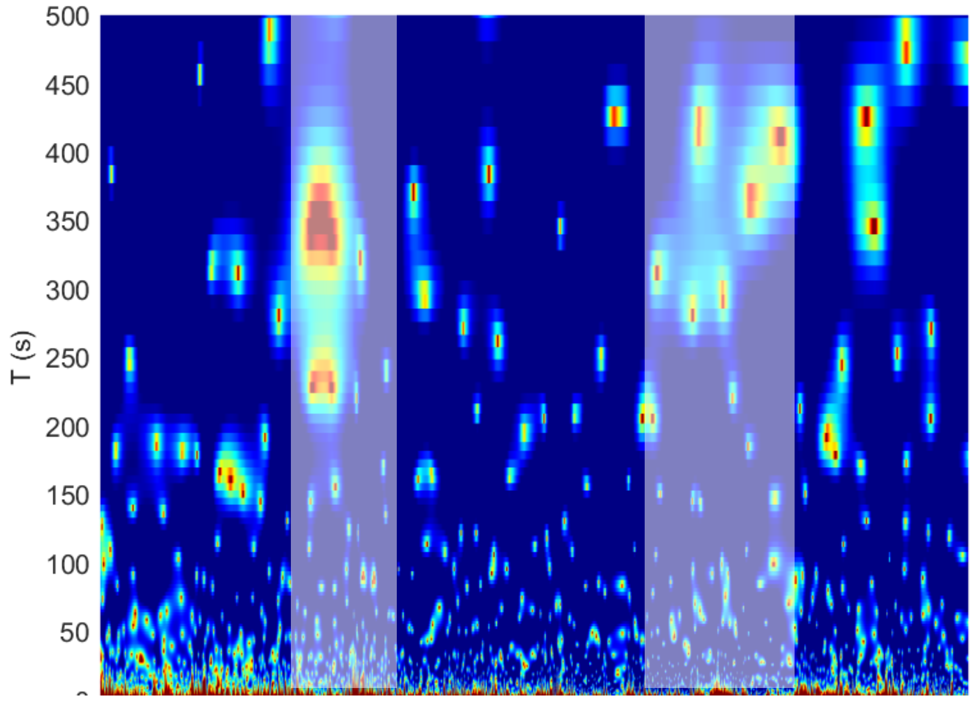
Conclusions

Under the same wave conditions, the propagation patterns, the interaction with the coastal promenade, and the resulting overtopping/flooding differ substantially, being absent at low tide but strongly exacerbated at high tide.

This experiment shows that assuming a fixed sea level for an hourly sea state compromises the realism of the interaction between wave dynamics, sea level, and the emerged shoreline. As a result, it underestimates flooding during low tide and overestimates overtopping and flooding during high tide, not only due to the longer exposure time but also owing to a ‘**repetitive saturation**’ of setup, surf-beat, and overtopping processes, **acting simultaneously** caused by the absence of spatial migration of the breaking zone

Conclusions





Ongoing work

Acquire instrumental data on waves and overtopping/flooding in order to ensure the reliability of the predictions.

Analyze the influence of using non-fixed bathymetries in the procedure and analysis

Expand the catalogue of combinations of wave heights, periods, directions, and water levels.

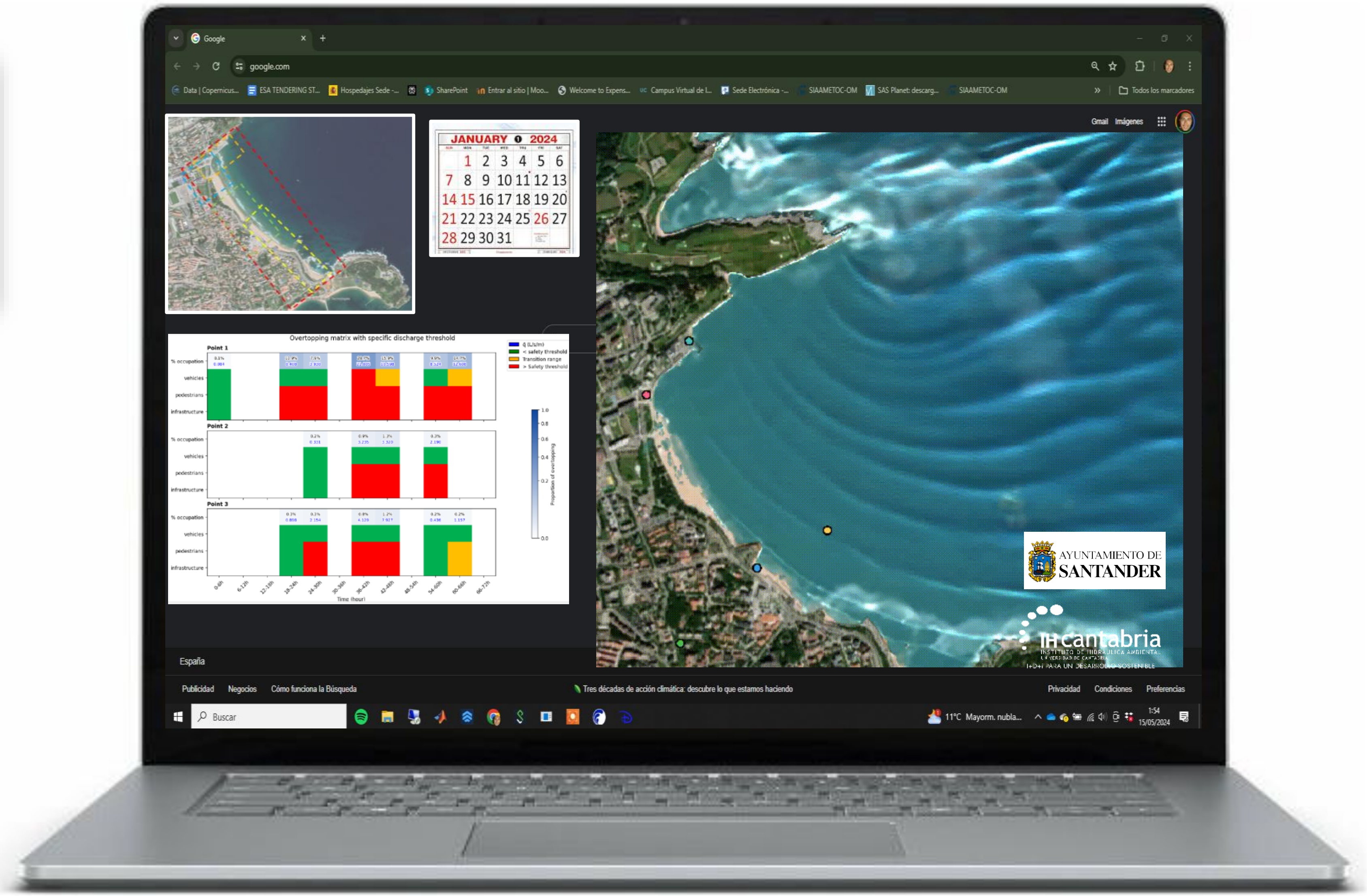
Integrate the system into a predictive protocol at the level of an early warning system

Integrate the assimilation of results into the Santander City Council's emergency plan

Ongoing work

Proof of concept

DIGITAL TWIN AGGREGATE



Muchas gracias

Ongoing work