

# Towards assessing the contribution of far and near field wave families on coastal erosion and flooding in the Gulf of Panama

**Presenter:** Ruby Vallarino-Castillo

**Position:** PhD Candidate

**Institution:** Universidad Politécnica de Madrid

## MOTIVATION & RESEARCH GAP



Gulf of Panama, is  
a semi-enclosed  
tropical basin in  
Central America



Beaches experience  
shoreline erosion of  
up to 2.0 m per year



Most of the beaches  
affected are major  
contributors to  
Panama's tourism  
economy



**Research gap:**  
Exploring wave climate multimodality  
at the Gulf of Panama

## Towards assessing the contribution of far and near field wave families on coastal erosion and flooding in the Gulf of Panama

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### 1 MOTIVATION & OBJECTIVES

The Gulf of Panama is increasingly vulnerable to coastal hazards, with erosion rates up to ~2.0 m/year impacting communities and infrastructure. Coastal wave dynamics are complex and multimodal, influenced by long-period swells, regional storm waves, and local wind-driven systems. Understanding these interactions is essential for assessing coastal risks and supporting management strategies in this semi-enclosed tropical basin.

#### Research Gap:

Previous studies have focused mainly on single-point offshore measurements, limiting understanding of how multiple wave systems interact near the coast. While multimodal wave dynamics are recognized, there is limited analysis of their behavior at the entrance of the Gulf of Panama, and no detailed assessment has yet explored how these systems propagate within the semi-enclosed basin to influence coastal conditions.

#### Research Objective:

This study focuses on characterizing multimodal wave dynamics at three representative points at the entrance of the Gulf of Panama. Based on these findings, future work will extend the analysis into the interior of the gulf to investigate how existing wave families persist or new families develop, and how these processes may contribute to coastal impacts within the gulf.

### 2 RESEARCH DESIGN

#### First research (completed):

- Data:** Wave spectra from the GLOSIVAC-5 atlas (1969–2023).
- Wave systems:** Multimodal sea states analyzed at three entrance points of the Gulf of Panama (1969–2023).
- Patterns:** Waves classified as following, crossing, opposing to capture seasonal variability and drivers.
- Trends:** Long-term changes in  $H_s$  and  $T_p$  assessed in three periods (dry vs. wet season).
- Extremes:** Quantile regression (50th, 95th, 99th) used to detect shifts in typical and extreme events.

#### Second research (ongoing):

- Data:** Wave systems identified from GLOSIVAC-5 at the gulf entrance.
- Propagation model:** Wave fields were propagated into the Gulf of Panama using Brinkmann, an additive hybrid method.
- Selection of analysis locations:** based on dates of extreme wave events to capture the areas most affected by high waves.
- Spatial framework:** The selected regions are subdivided using an HD hexagonal grid (size 5) to evaluate spatial variations in wave conditions.

### 3 RESULTS

#### First research (completed):

- Hs trends:** WSI shows consistent increases in median and extreme  $H_s$  across all sites, especially during the wet season (May–Nov). From 1969–1987,  $H_s$  rose ~5 cm at sites 1–3; by 2006–2023, wet-season  $H_s$  increased >10 cm, with extremes >2 m. WSI shows dry-season (Dec–Apr) increases of 5–10 cm at sites 1–2, weaker at site 3. WSI2 and WSI4 peak in the wet season, reaching ~1.25 m (95th percentile) in earlier periods, decreasing in 2006–2023. WSI5 is episodic, with sporadic extreme events (>0.26 m) mainly at sites 1–2.

- Tp trends:** WSI1 wet-season  $T_p$  increased by ~0.4–0.8 s, leading to higher wave energy. WSI4 shows moderate, site-specific increases (~0.3–0.8 s). WSI2 and WSI3 remain mostly stable, while WSI5 changes are spatially variable, with no clear pattern.

- Implication:** Wet-season wave energy in the Gulf of Panama has risen in recent decades, enhancing coastal erosion, flooding, and sediment mobilization, with site- and system-specific differences.

#### Second research (ongoing):

- Wave propagation simulations for selected extreme events show that wave energy concentrates in areas already affected by coastal flooding and erosion. The Gulf's bathymetry and morphology guide incoming swell from the entrance, focusing wave energy on vulnerable shorelines.

### Flooding and erosion repeatedly affect coastal communities in Panama, especially those in the Gulf of Panama



### 4 FUTURE RESEARCH

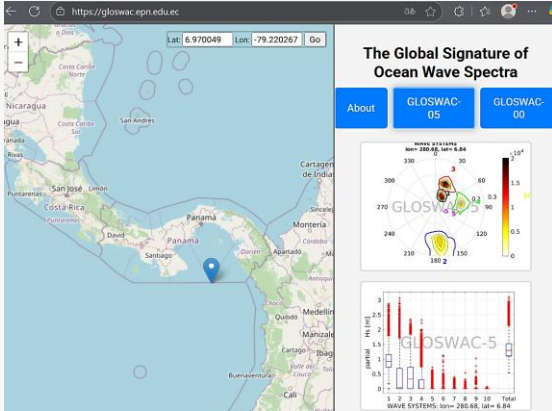
- Extend the analysis of wave families into the interior of the Gulf of Panama.
- Investigate how existing wave systems persist, evolve, or generate new families.
- Assess how these processes contribute to coastal impacts and vulnerability.

### 5 REFERENCES

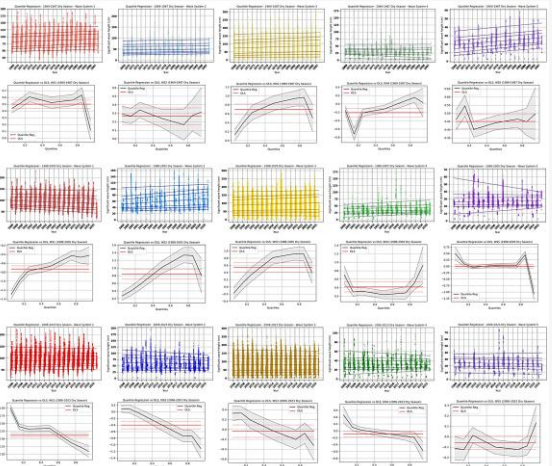
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- Cagigal, L. (2024). *Beillevue: An additive hybrid method to decompose directional wave spectra to nearshore areas*. *Ocean Modelling*, 189, 102346. <https://doi.org/10.1016/j.oceanmod.2024.102346>

# RESEARCH DESIGN

## First research (completed):



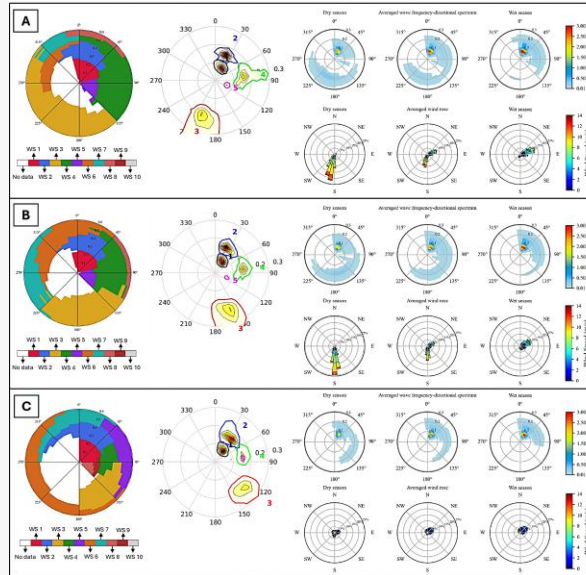
## GLOWAC-5 Atlas <https://glosvac.epn.edu.ec/>



## Wave system patterns shaped by seasonality and Gulf of Panama geomorphology

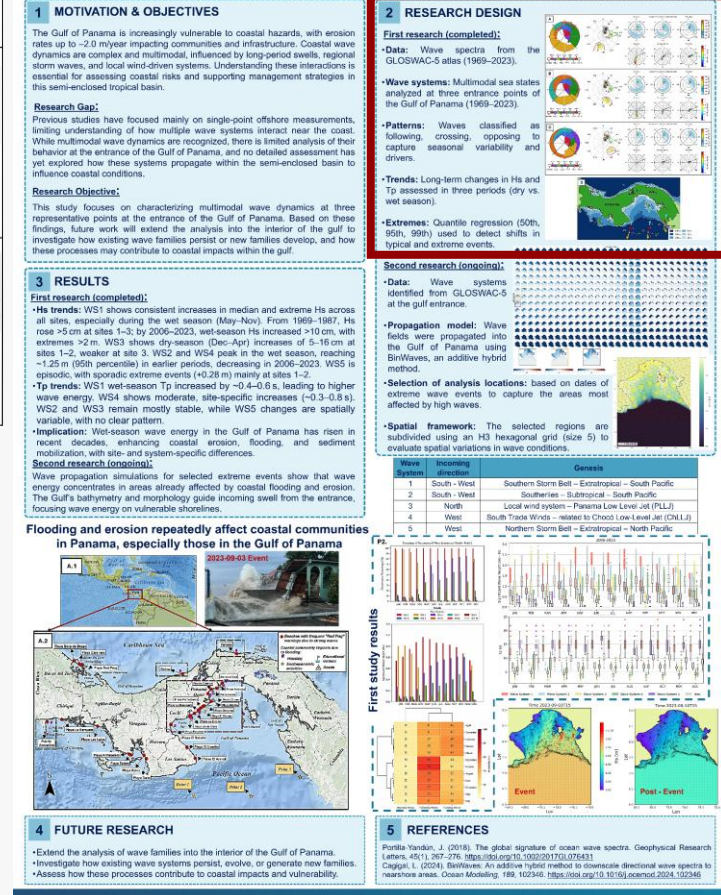
## Quantile regression to analyze long-term changes, between three periods and season

## Quantile regression captures changes across the whole distribution



## Towards assessing the contribution of far and near field wave families on coastal erosion and flooding in the Gulf of Panama

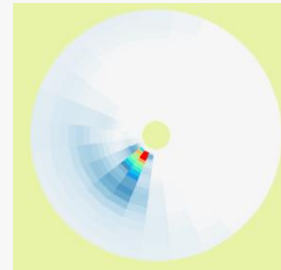
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## Second research (ongoing):

## Offshore directional wave spectrum



BinWaves: disaggregation of the full directional wave spectrum into monochromatic bins, simulation with SWAN to derive propagation coefficients ( $K_p$ ), and superposition of bins to reconstruct nearshore spectra

After reconstruction, we used the H3 grid to select hindcast points for spatial wave variability analysis.

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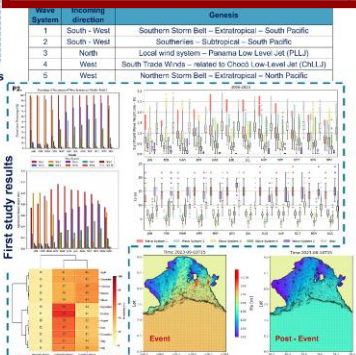
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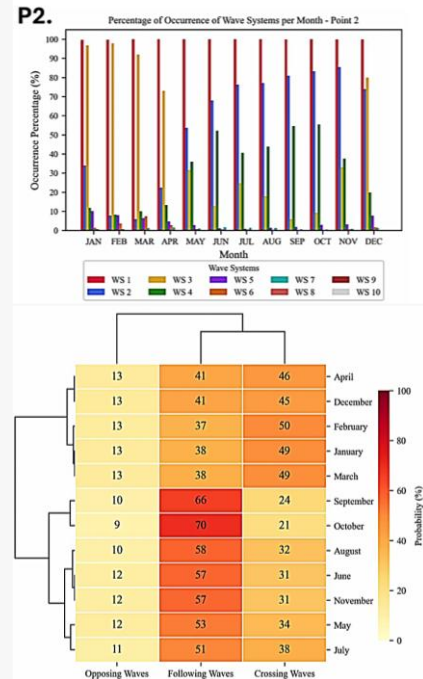
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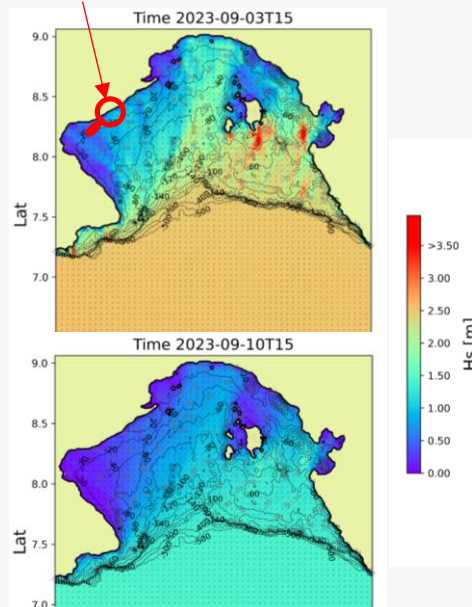
## RESULTS:

### First research (completed):

- WS1 dominates year-round.
- WS2–WS4 are strongly seasonal.
- Wave trains reflect monthly and seasonal climate.



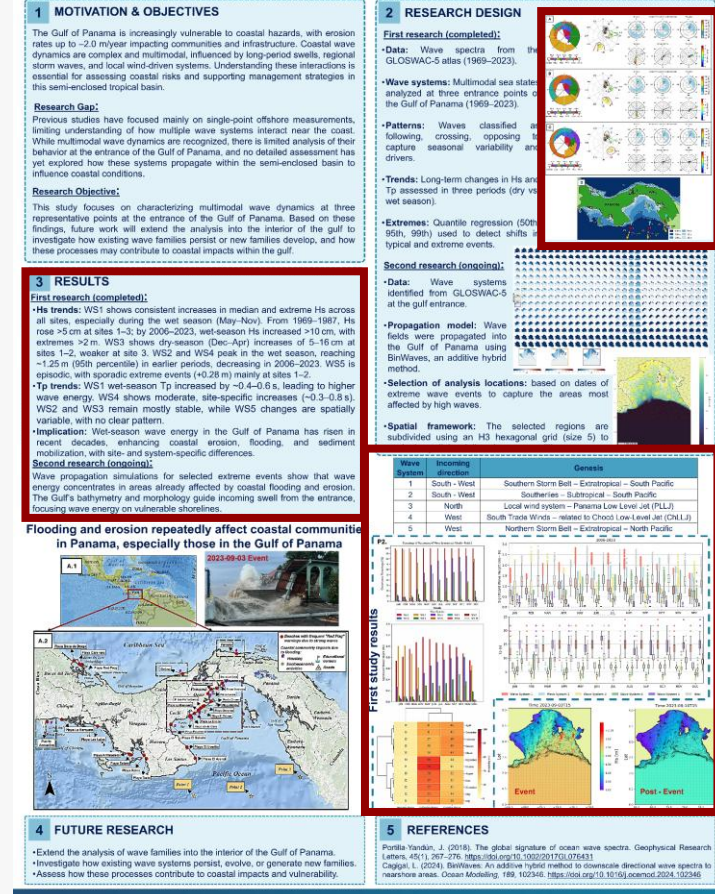
### Second research (ongoing):



Wave energy concentrates in areas already affected by coastal flooding and erosion

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## FUTURE RESEARCH

- **Reconstruct a detailed spectral hindcast for the interior of the Gulf of Panama, providing data not yet available at this scale.**
- **Explore wave systems in the interior of the Gulf of Panama.**
- **Investigate how wave dynamics influence vulnerable beaches within the Gulf.**

## REFERENCES

**GLOWAC-5 atlas:**

**Portilla-Yandún, J. (2018).** The global signature of ocean wave spectra. *Geophysical Research Letters*, 45(1), 267–276. <https://doi.org/10.1002/2017GL076431>

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