From coastal storms to shoreline erosion:

Developing a machine learning-based predictive model

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Introduction

- How do extreme wave events reshape our coasts?

- Can we move beyond forecasting waves to predicting their impacts?

Extreme Weather Event
"An event that is rare at a particular place and time of year. Definitions of 'rare' vary, but an extreme weather event would normally be as rare as, or rarer than, the characteristics of what is called extreme weather may vary from place to place in an absolute sense"
(AR6 - IPCC, 2023)

From Microsoft stock images.

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Introduction

Extreme Impact

"Highly significant, often long-lasting consequences for society, the environment, or ecosystems. They may result from a single extreme event or from successive events (climatic or non-climatic)."
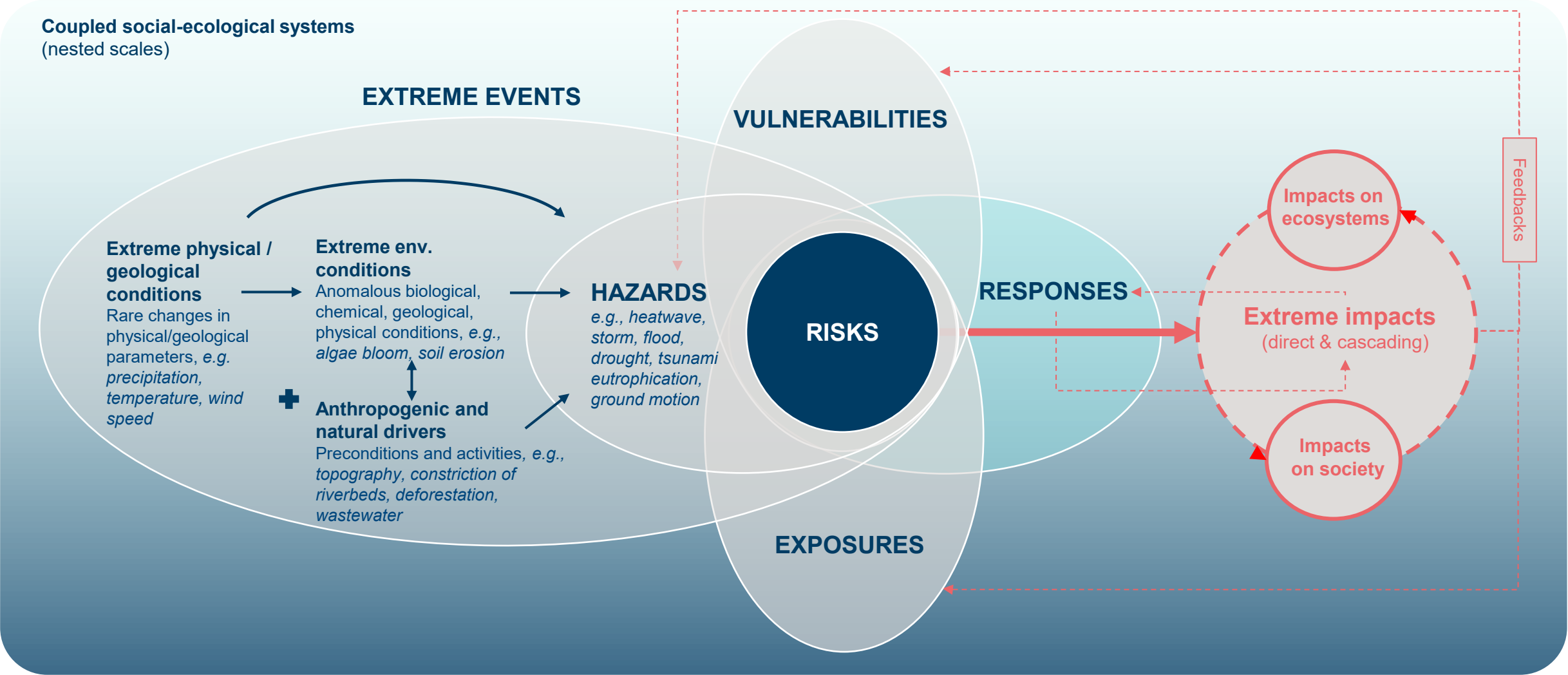(SREX – IPCC, 2012)

Key concerns
- Early warning requirements
- Beach & dune erosion
- Drainage-related impacts

Beach section on the Norderney Island. ©www.moin.de
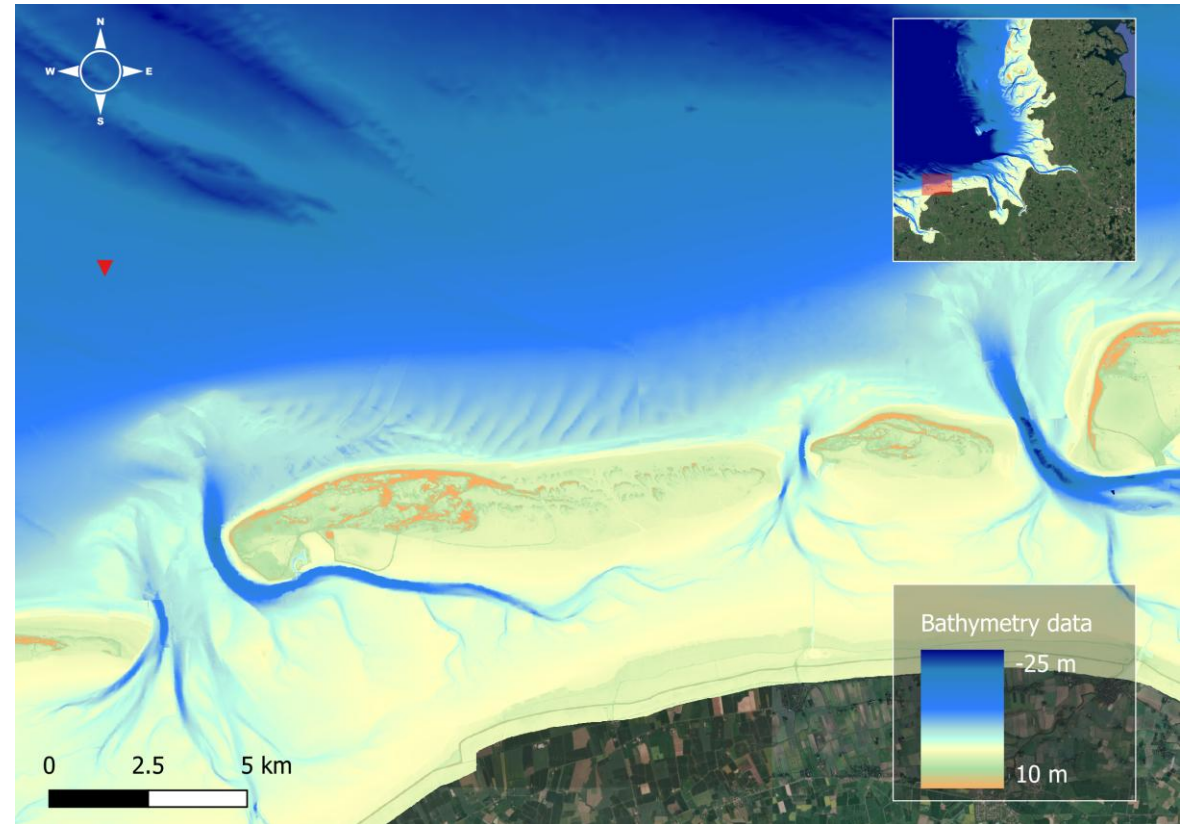
Extreme Events → Extreme Impacts

©Fabian Rackelmann (ElbeXtreme project), Conceptually placing "extreme events", from the Risk conceptualisation IPCC AR6 2022.

Study site

Norderney (East Frisian Islands, Germany)

- Storm Impacts: Focus on coastal storms affecting Norderney.

- Wave Data (1948–2023): Hindcast dataset (WAM model) at grid point (Lon: 7.0903, Lat: 53.7675) → ML predictands.

- Validation: In situ data from SEE buoy (NLWKN).

- Captures temporal distribution and characteristics of coastal storms near the island.

Norderney island in the Wadden Sea. Red marker indicates the point of interest (waves)

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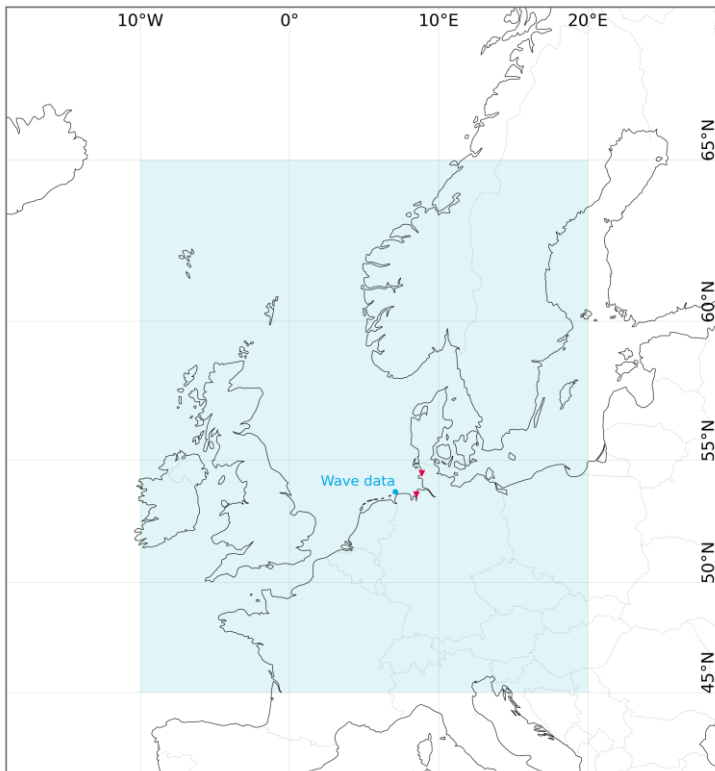
Ebb-tidal Delta

- Sand body in front of tidal inlets on sandy coasts

- Shapes coastal erosion, navigation, and ecosystems

- Highly dynamic → shoal and channel migration (often clockwise)
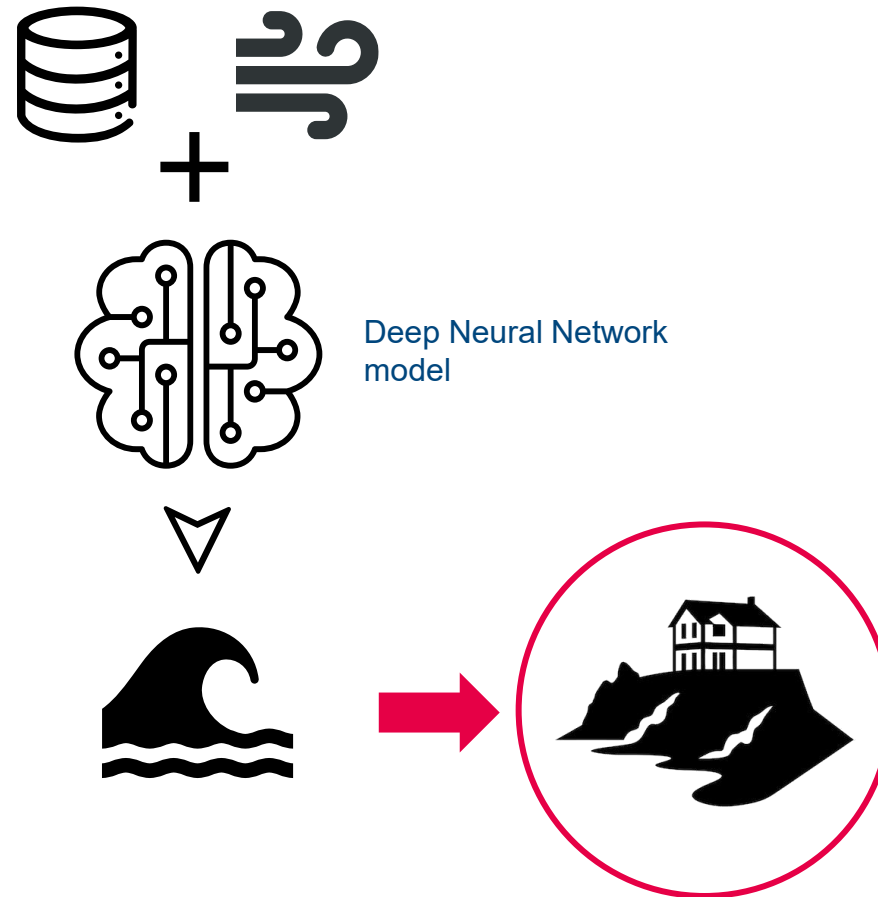
- Sediment pathways still poorly understood!
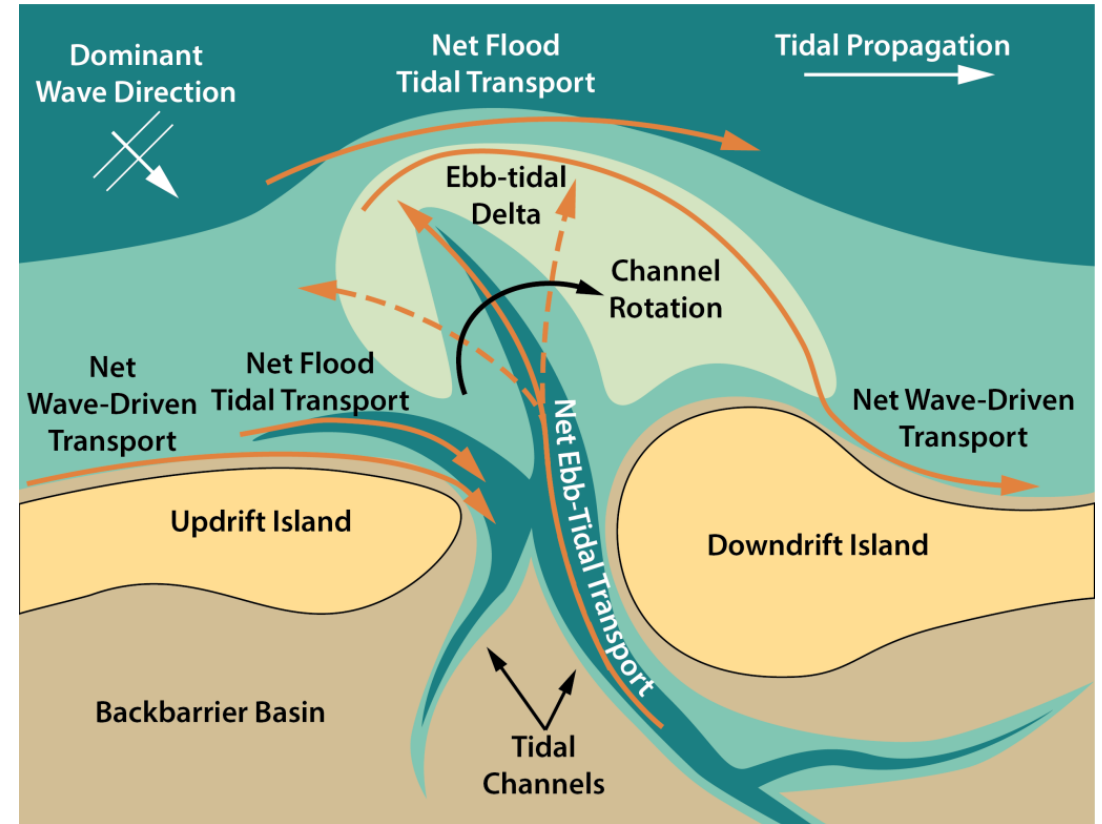
Morphodynamic behaviour of ebb-tidal deltas ©Stuart Pearson, coastallycurious.com

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Impact-based Forecast system

Offshore Sea State Prediction:
Meteorological data drives wave forecasts.

From "what will happen" → "what it will do to the coast"

Deep Neural Network model

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Extreme wave events

Event identification criteria:

- Long-term 75% (1.48 m) & 95% (2.48 m) percentiles
- Minimum duration of 6 h, with at least 24 h between events
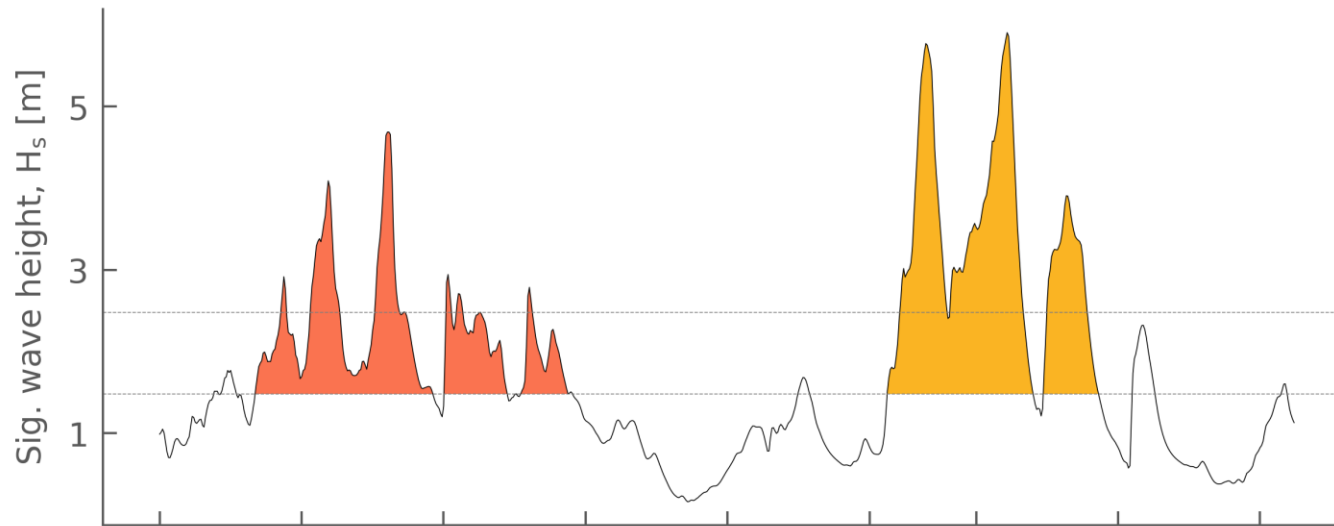
Extreme wave events: Significant wave height-based storm identification approach, minimum duration is 6 hours.

Linking extreme waves to shoreline change

Extracted from satellite images
Purpose: Connect wave/storm events to observed coastal impacts

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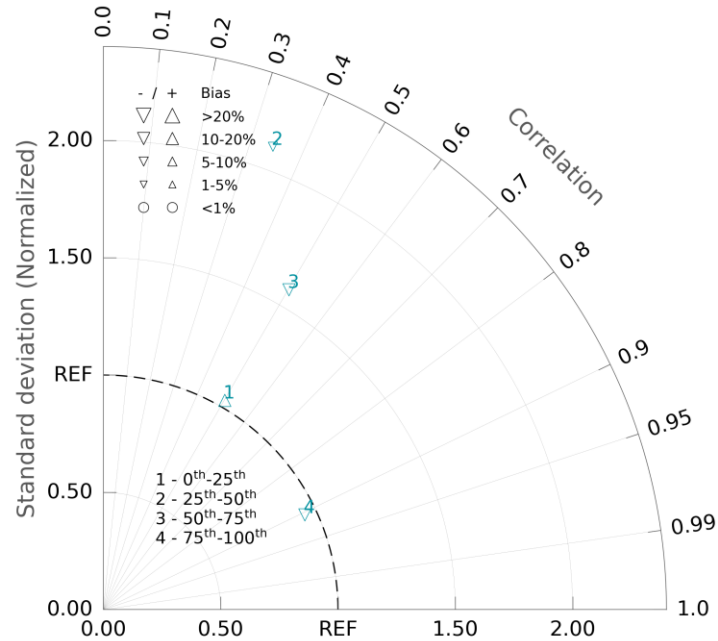
Shoreline data extractions

- Toolkit: CoastSat (Python-based, open-source)

- Data Sources: Landsat 5, Sentinel-2

- Time Span: 1984–2024

- Total Extractions: 658 shoreline positions

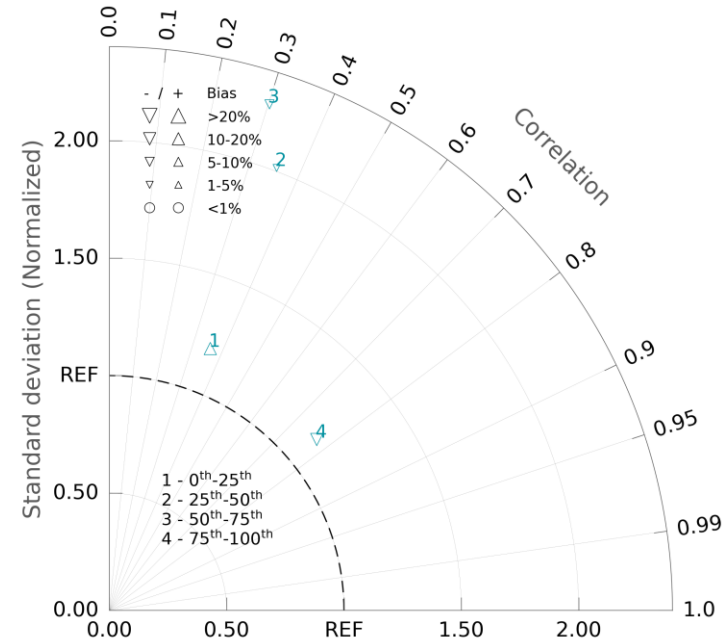- Example: September 2016
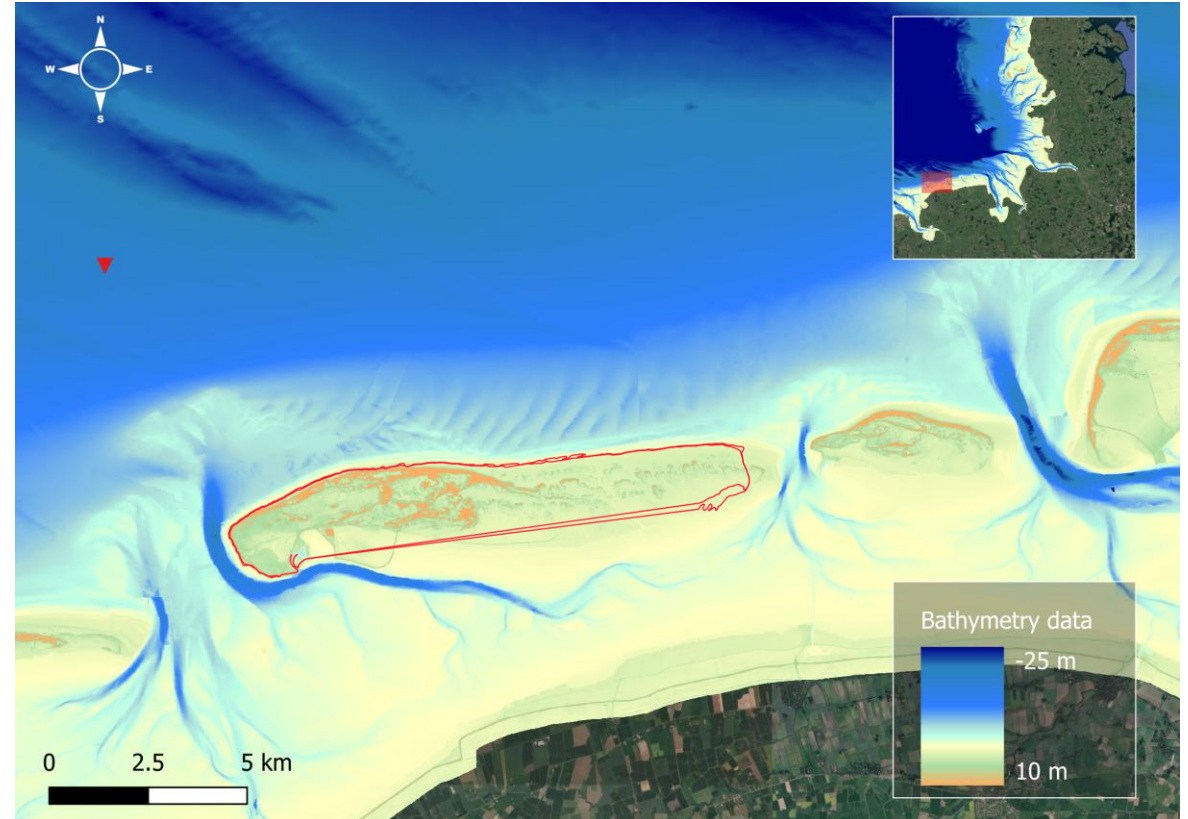
Shoreline extractions from CoastSat.

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IBF system: Wave storm predictions

Significant wave height

Wave height predictions from the ML model

Wave period

Wave period predictions from the ML model

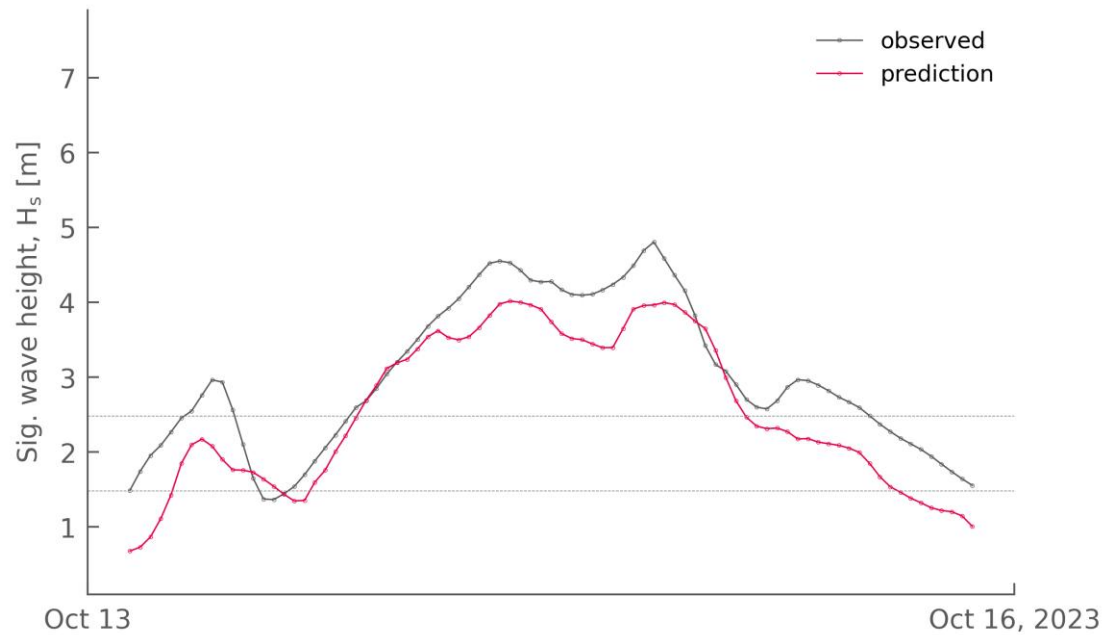©Salika Thilakarathne   22.-26.09.2025, 4th International Workshop on Waves, Storm Surges and Coastal Hazards

IBF system: Wave storm predictions

Wave direction
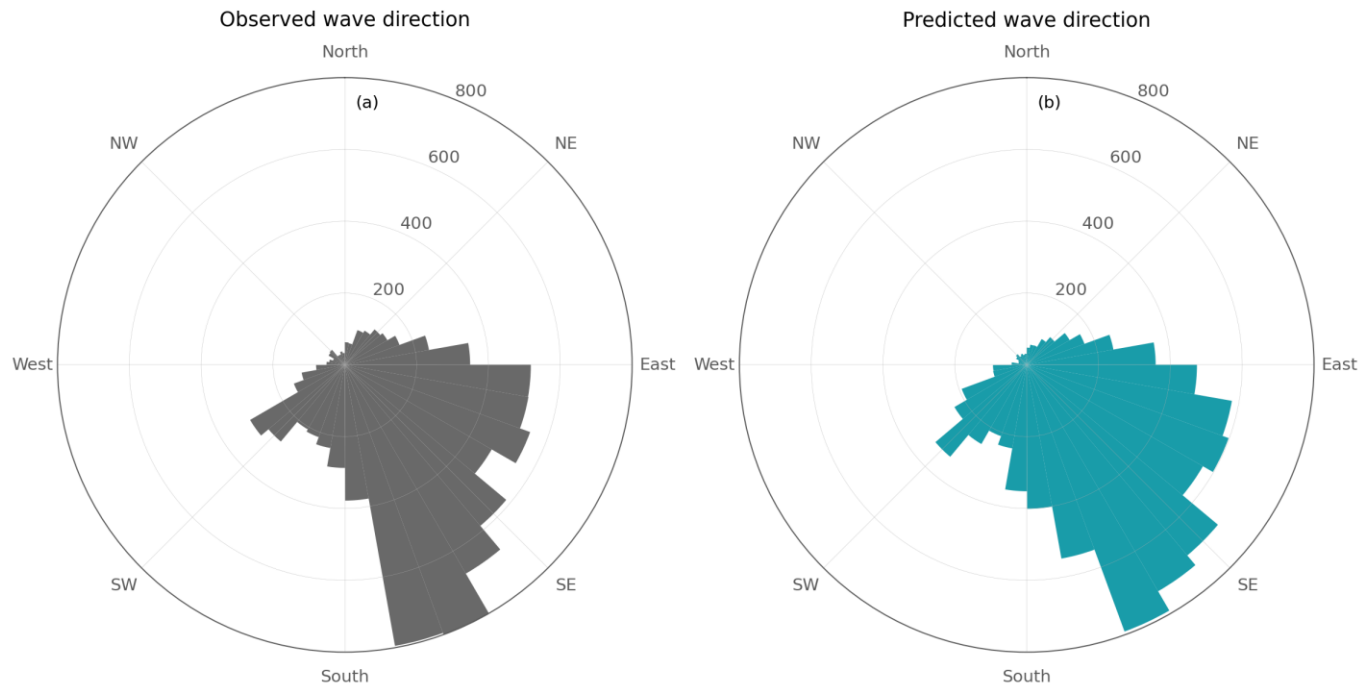
Polar histograms of wave direction predictions from the ML model

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IBF system: Wave storm predictions

Low pressure system TINO
13-14 October 2023

Storm Zoltan
21-22 December 2023

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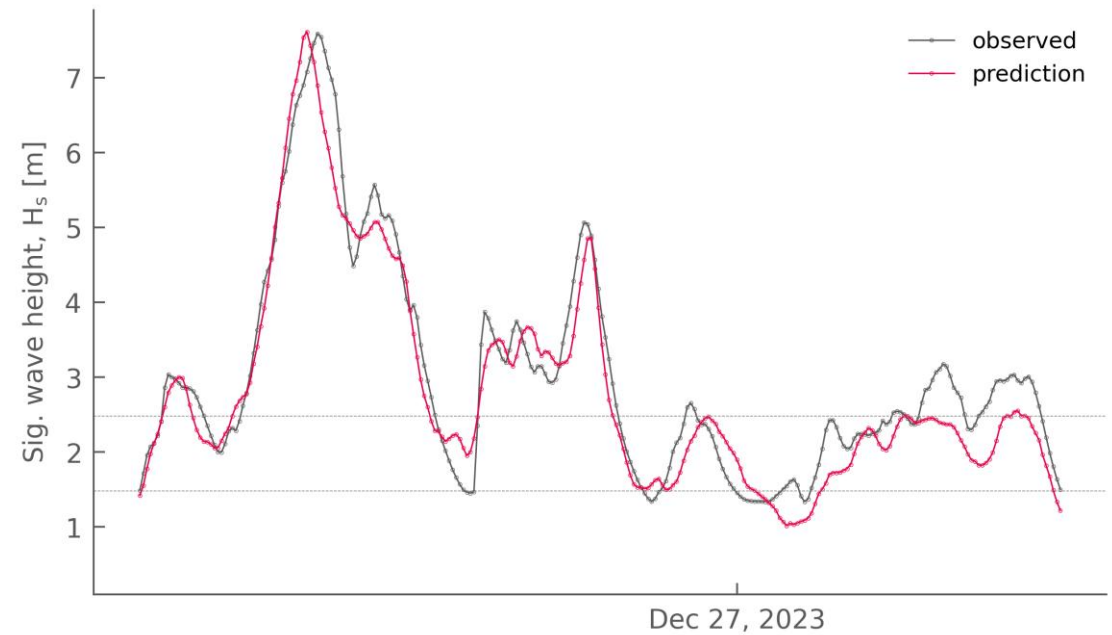
IBF system: Coastal impacts

- **Insufficient** for ML training: <50 usable shorelines out of ~650 extractions

- Next Steps: Collaborate with local coastal agency to obtain higher-quality data

- Takeaway: Data quality is the main bottleneck for predictive modelling—addressing this is key for future work.

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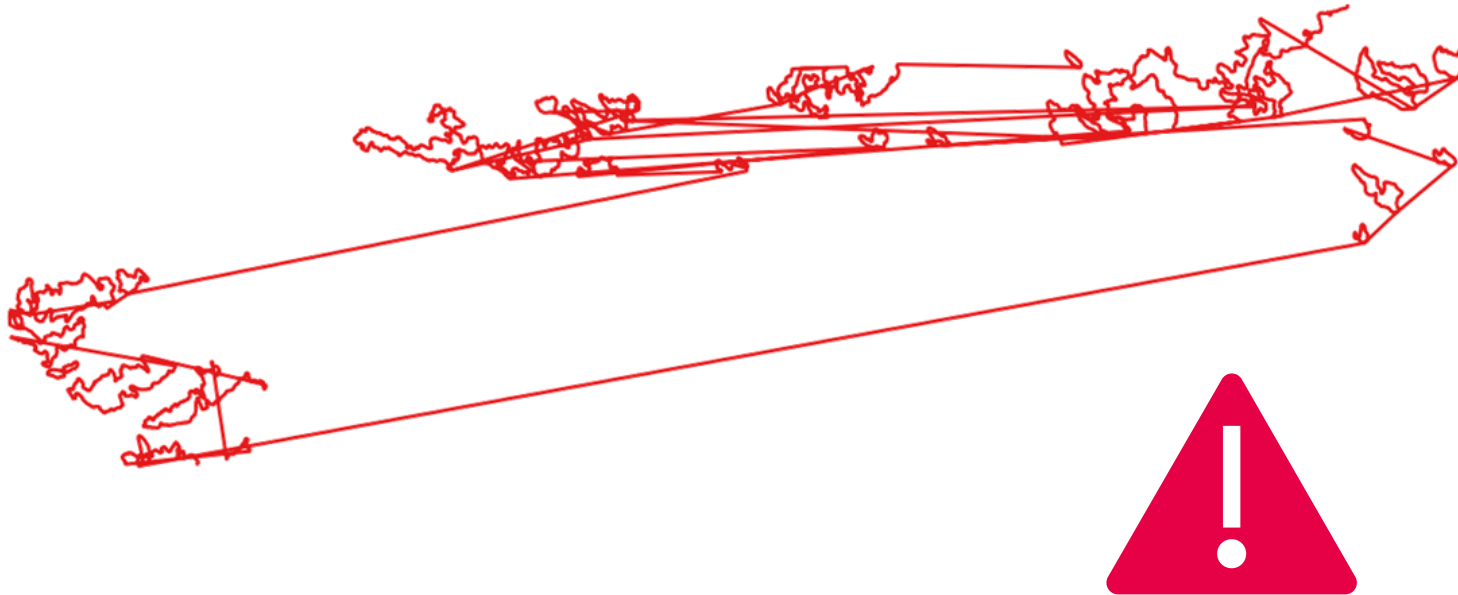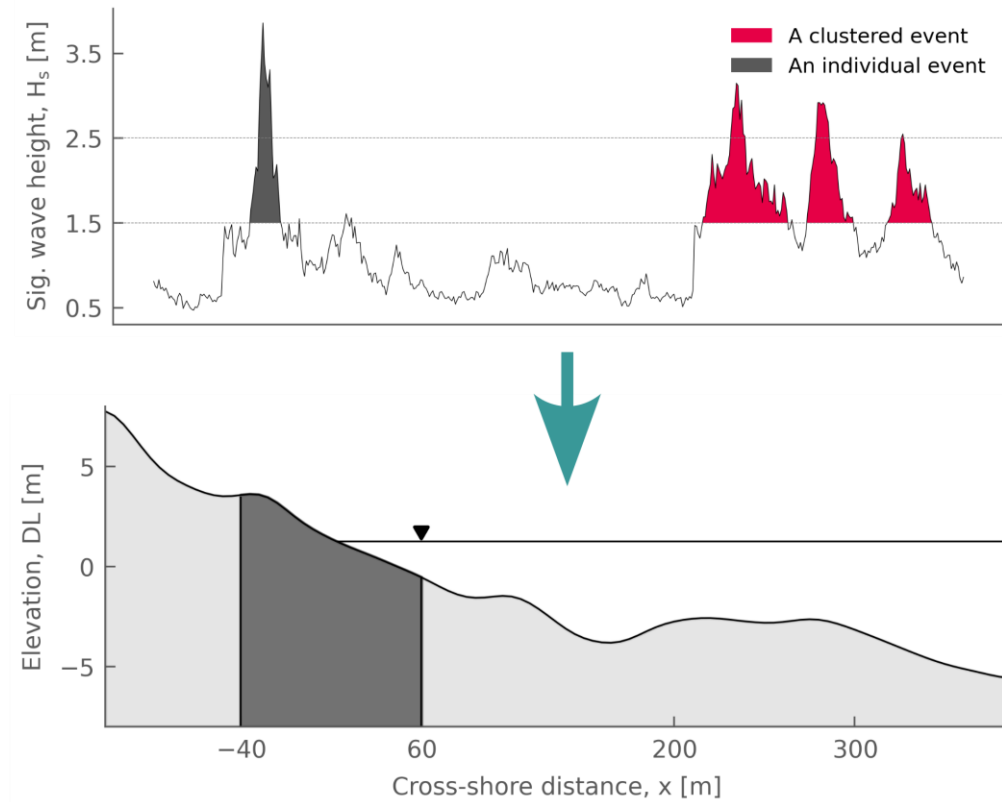
Next steps

- **Simulated Shoreline Datasets**: Generate extensive time series for ML training

- ML-Driven IBF Model: Explore feasibility, constraints, and data/resource needs

- Combine with seasonal ensemble forecasts (**Living Lab applications**)

- **Storyline-Based Approaches**: Focus on extreme wave conditions during selected storm events
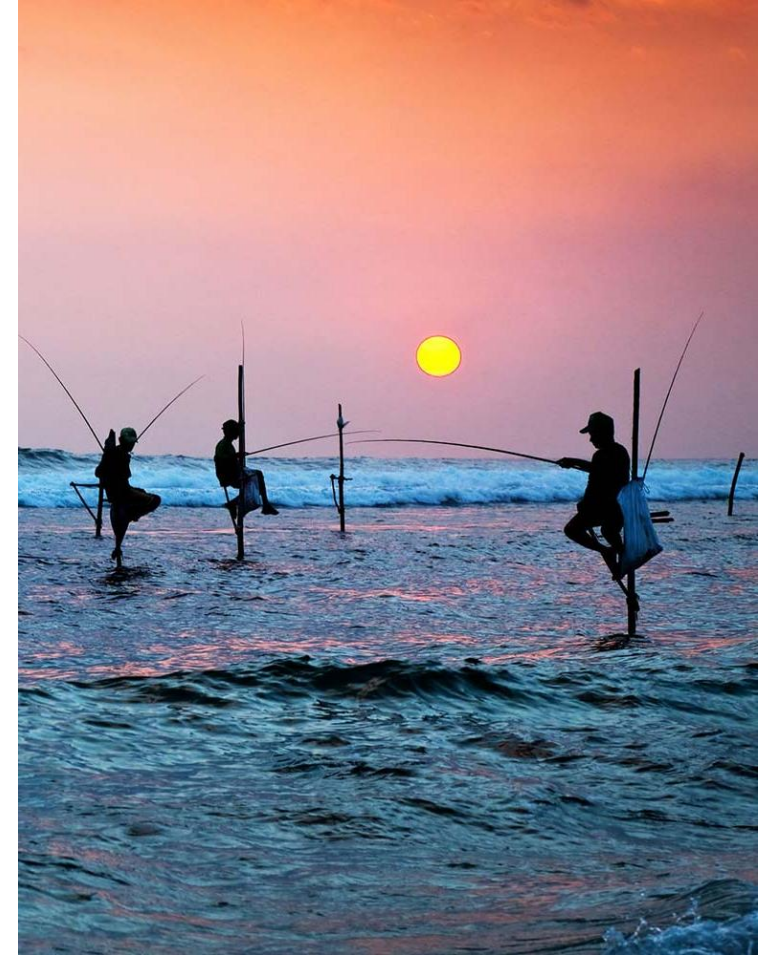
Stilt fishermen in Sri Lanka. ©harithavillas.com

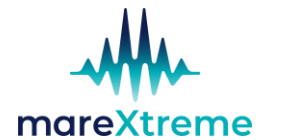22.-26.09.2025, 4th International Workshop on Waves, Storm Surges and Coastal Hazards

Our recent work

Wave storm dynamics and clustering, and their impacts on beach erosion

https://doi.org/10.1017/cft.2025.10012

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Thank you!

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