Università di Genova | **DICCA** DIPARTIMENTO DI INGEGNERIA CIVILE, CHIMICA E AMBIENTALE

EVAN 2026 — ADVANCES IN EXTREME VALUE ANALYSIS AND APPLICATION TO NATURAL HAZARDS

MeteOcean

A Data-Driven Framework for Directional Extreme Wave Analysis Using Density-Based Clustering

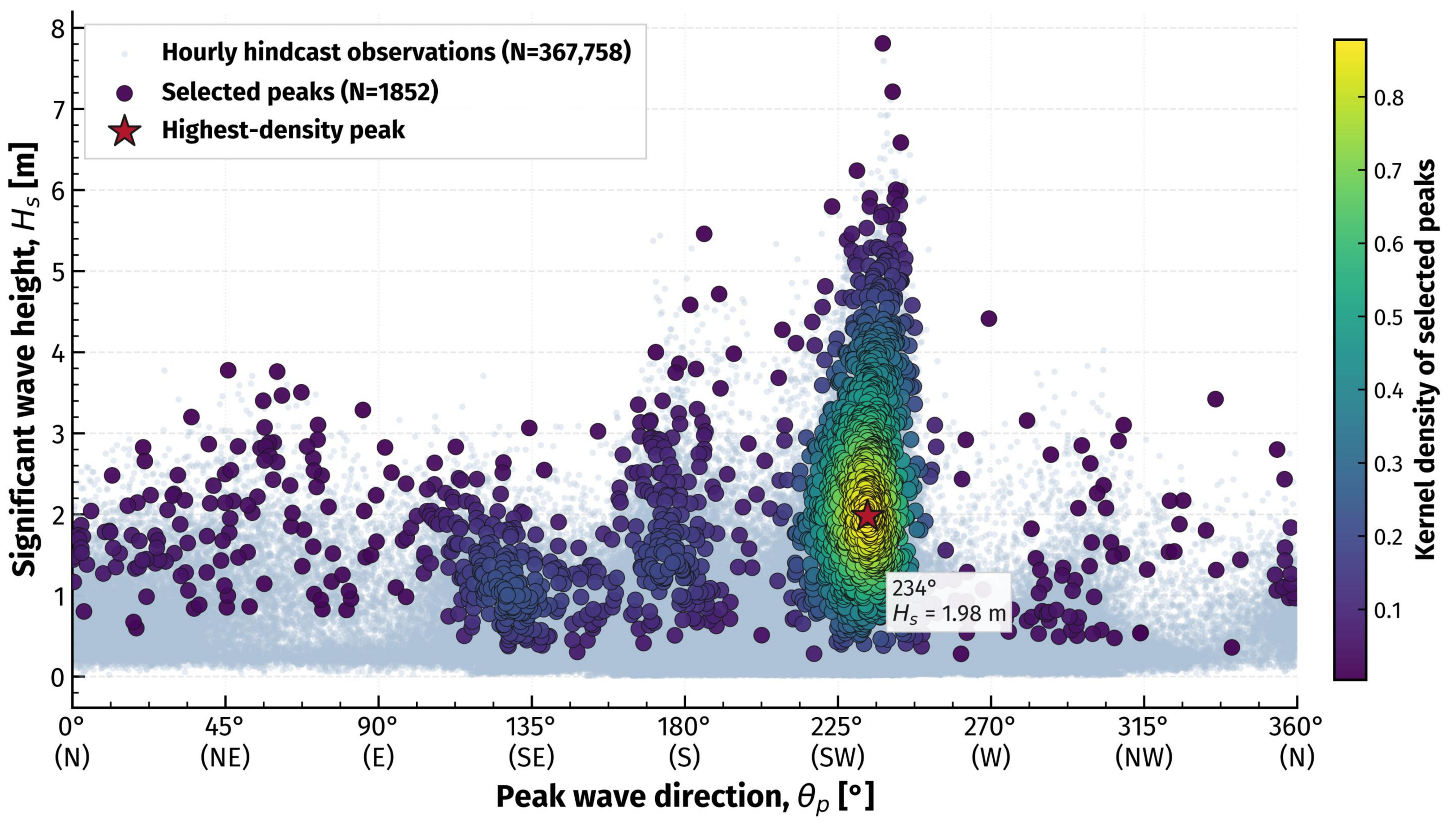
Iremnaz Kosem, Giovanni Besio, Francesco De Leo

This study presents a fully data-driven framework combining **circular kernel density estimation (KDE), DBSCAN clustering, and directional extreme value analysis based on the Exponentiated Weibull distribution** to objectively identify dominant directional wave systems and estimate fetch-specific return levels.

The La Spezia case study demonstrates the complete workflow, while additional applications to Mediterranean sites with various shoreline orientations indicate that the methodology is **transferable across different coastal settings**.

Test Dataset	Hourly hindcast wave data
Location	La Spezia, Genoa, Italy
Temporal Coverage	01.01.1979 – 31.12.2020
Temporal Resolution	1-hour
Variables	Significant wave height, peak wave period, peak wave direction

Selected Peaks and Kernel Density Values | δ = 7 days | N = 1852 peaks



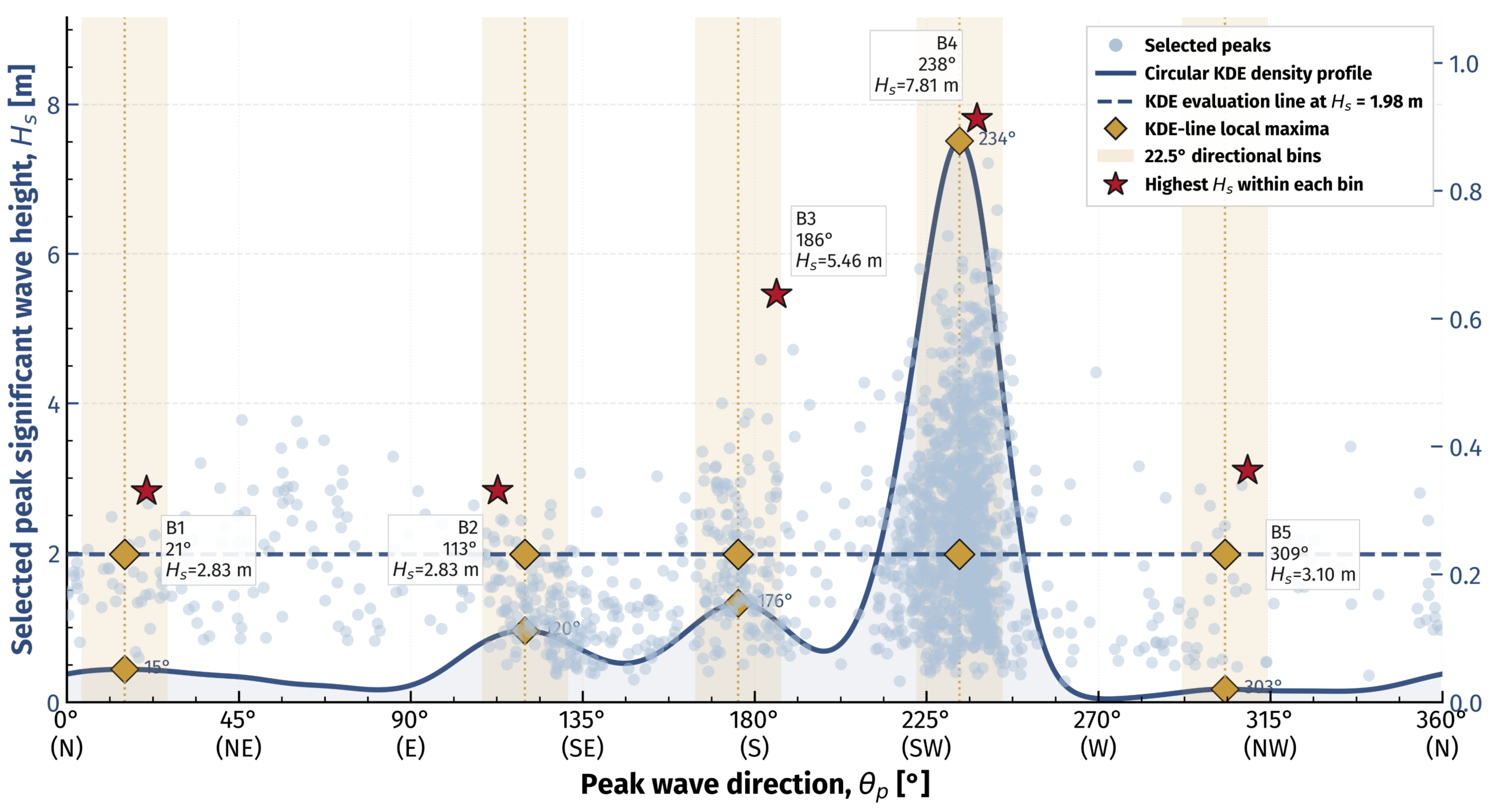
Directional Peaks Based on Kernel Density Values

- Peak events – Selected with the moving-window of 7-days
- Dominant directions – Identified based on the Kernel density value of each selected peak
- Directional peaks – Assigned to the highest waves in each 22.5-degree bin along the level of the peak with the highest Kernel density

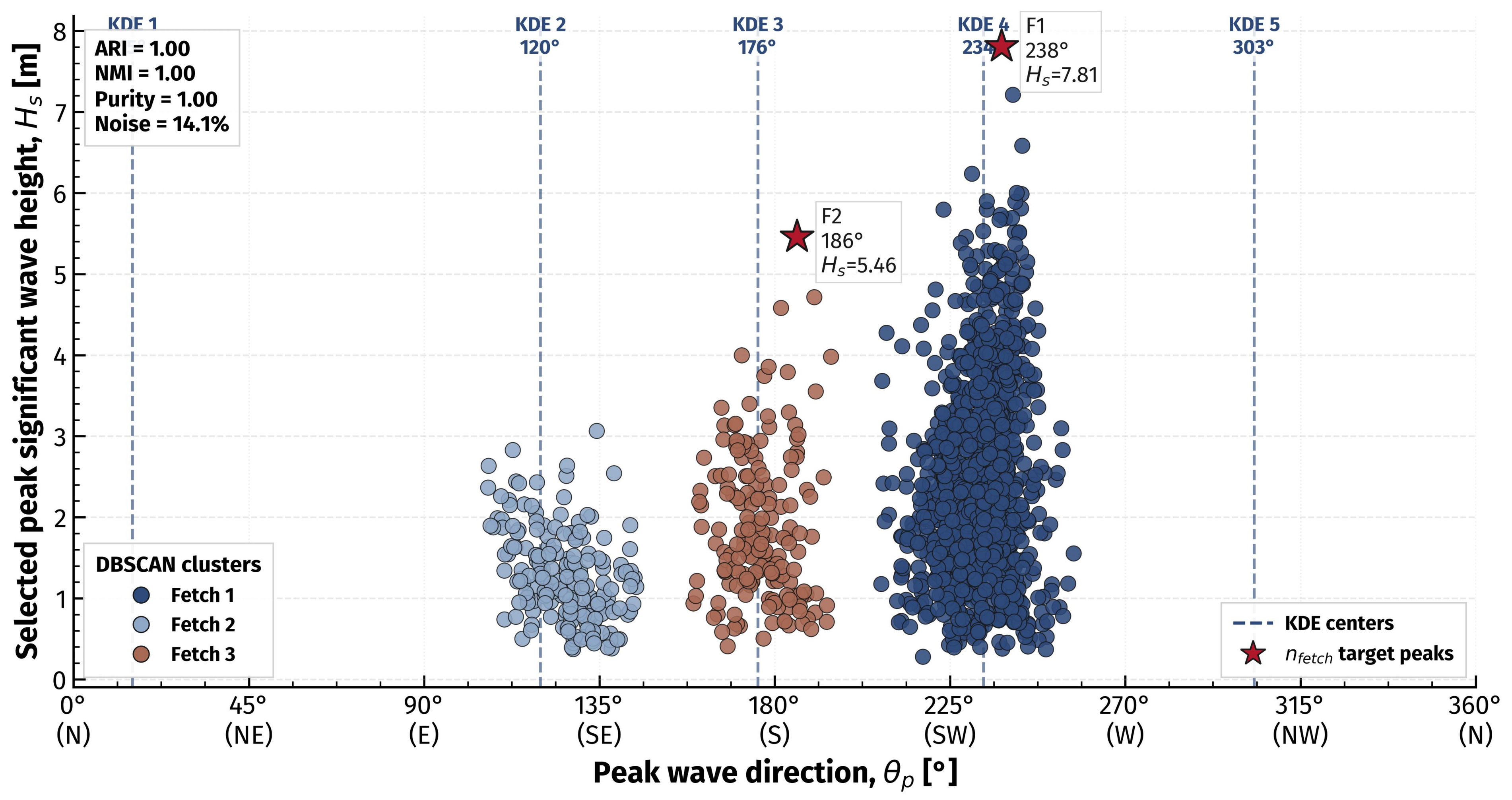
Fetch Detection with KDE-based DBSCAN

- Optimization of Density-Based Spatial Clustering of Applications with Noise (DBSCAN) Parameters – The consistency with the KDE-derived directional structure (ARI, NMI, and purity) is maximized, while the minimum noise ratio is aimed.

Circular KDE profile and 22.5° directional peak selection

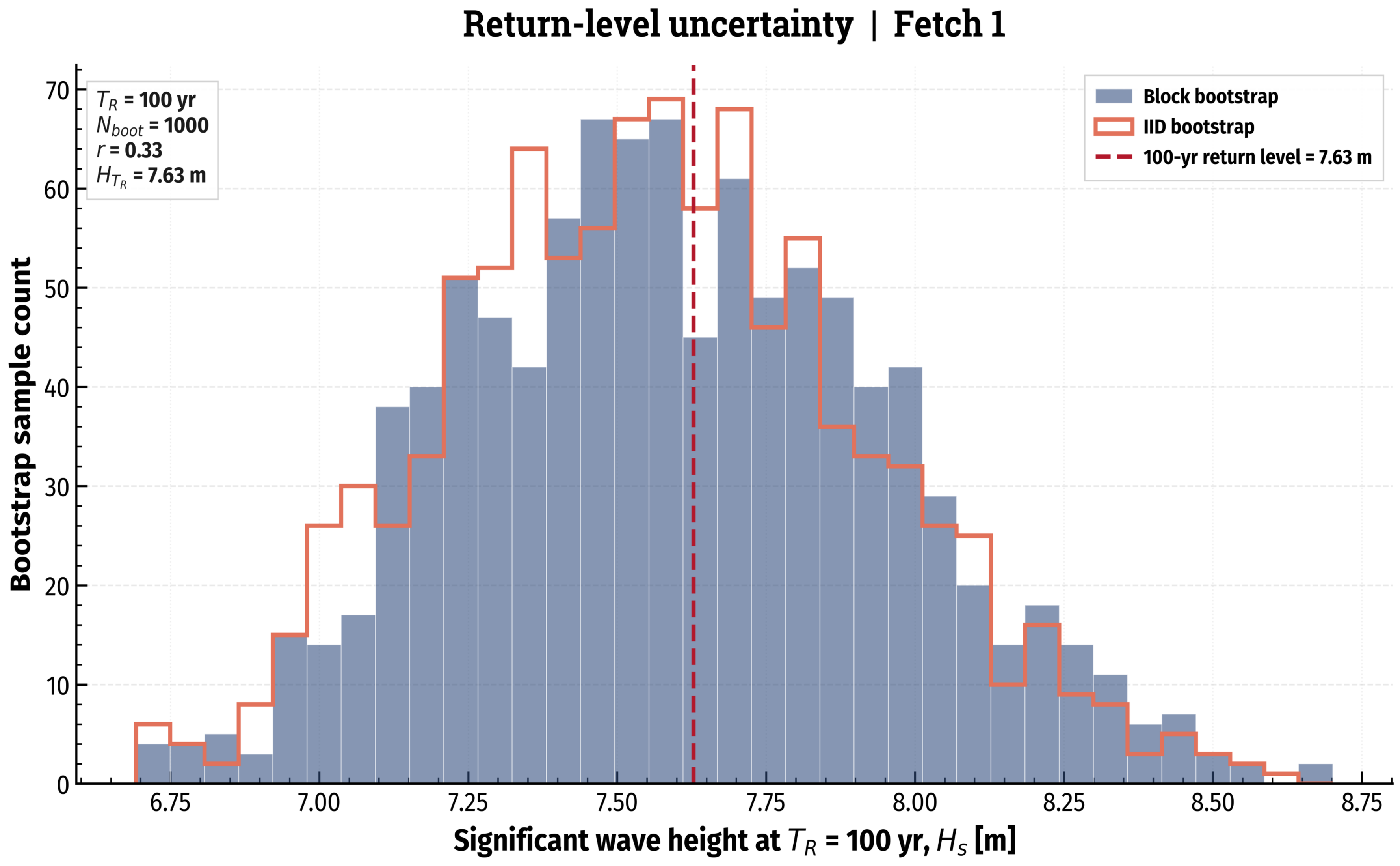


Best DBSCAN clustering | eps = 0.10, min samples = 40

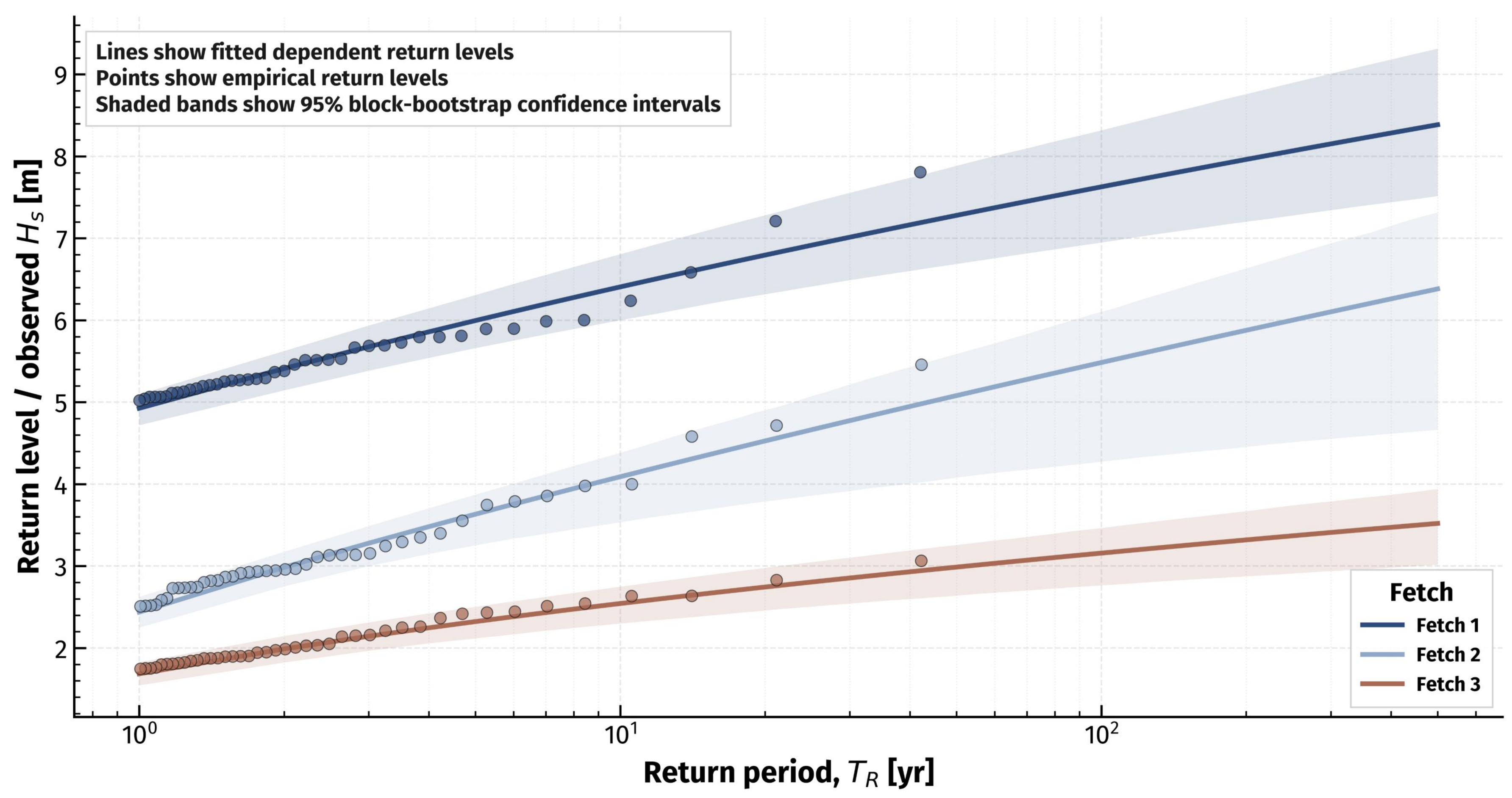


The extreme significant wave heights within each DBSCAN-derived fetch are modelled for each fetch fitting **the Exponentiated Weibull distribution**. Dependence-adjusted return levels are subsequently estimated using the **block bootstrap method** with uncertainty quantified through 95% bootstrap confidence intervals and validation against empirical return levels.

Return-level uncertainty | Fetch 1



Dependent and empirical return levels across selected fetches



References

Haselsteiner, A. F., & Thoben, K. D. (2020). Predicting wave heights for marine design by prioritizing extreme events in a global model. Renewable Energy, 156, 1146-1157.

Horowitz, J. L. (2001). The bootstrap. In Handbook of econometrics (Vol. 5, pp. 3159-3228). Elsevier.