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Emerging global ocean waves extreme spatial patterns through Bayesian Hierarchical Modelling

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Summary

-Motivations and objectives

-Methodology (Bayesian Hierarchical Model) and data (global wave models)

-Results: return levels,
trends, comparison with literature
comparison with point-based inference

-Conclusions and further work

Motivations

Extreme value analysis (EVA) of sea states is a building block of coastal engineering practice and oceanography. A large body of recent literature discusses EVA in non-stationary conditions due to wave climate modifications.

Open problems: current methodologies are based on local (individual mesh points, buoys), **spatial dependencies are not considered**.

Two types of dependencies in sea level/sea states extremes:

Residual: multiple locations affected by the same events (e.g. annual maxima are spatially correlated)

Climatological: locations have similar storminess but not necessarily co-occurrence of events (e.g. extreme value distribution parameters are correlated).

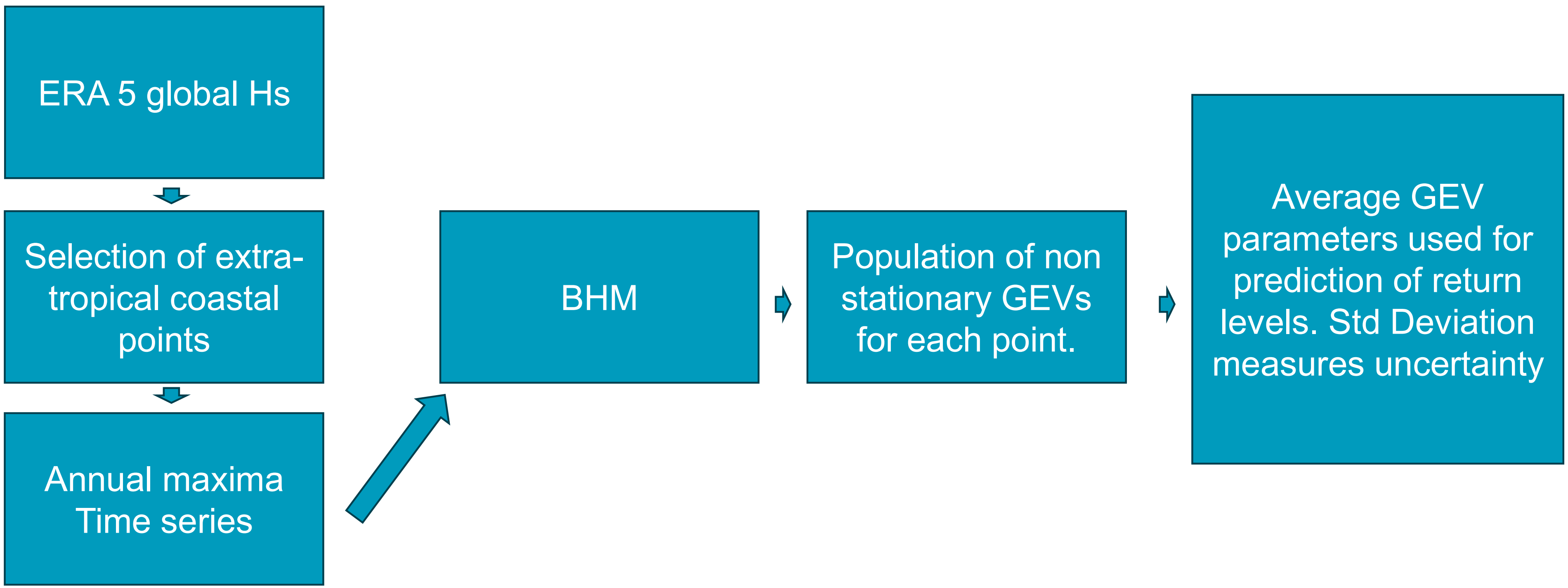
Objective: we want to quantify future extremes in sea state parameters taking into account spatial dependencies. To do so we first consider historical data and compare with the literature and point based inference (PBI) as validation.

Methodology

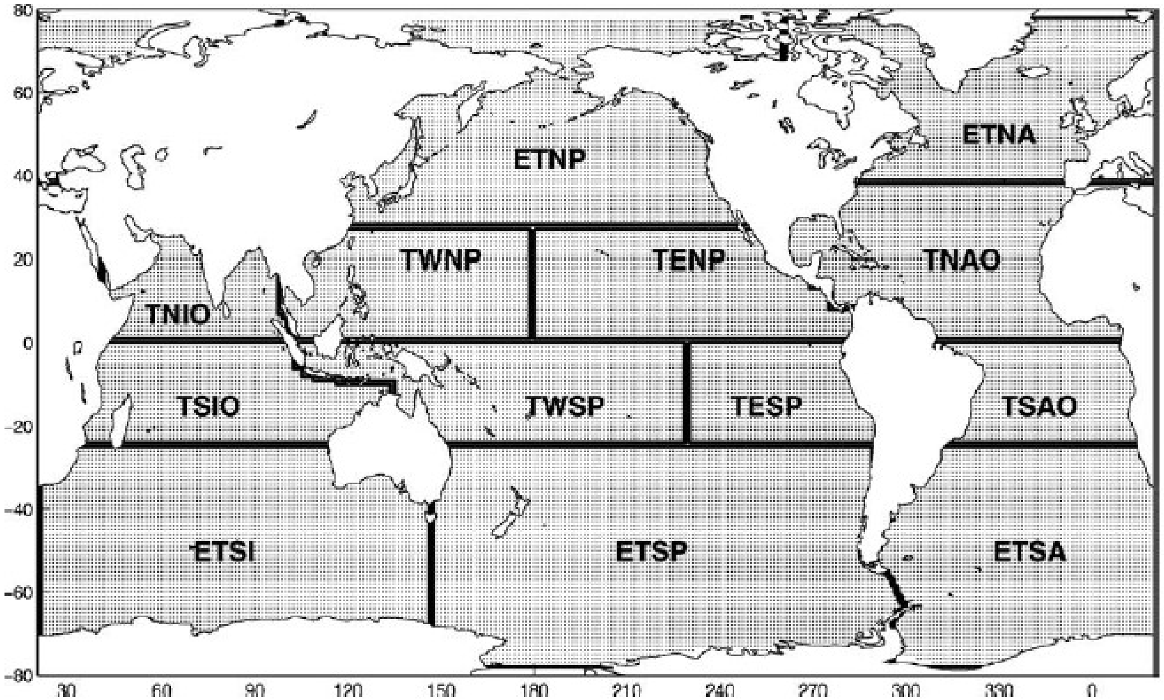
$$Y_t(\boldsymbol{s}) \sim GEV(\mu_t(\boldsymbol{s}), \sigma(\boldsymbol{s}), \xi)$$

Y_t (**s**) annual maxima observations, at a location **s**. μ_t(**s**) is the location parameter, σ(**s**) is the scale parameter, and ξ is the shape parameter.

μ_t(**s**) is allowed to change smoothly in time to capture trends (described as linear).



Data

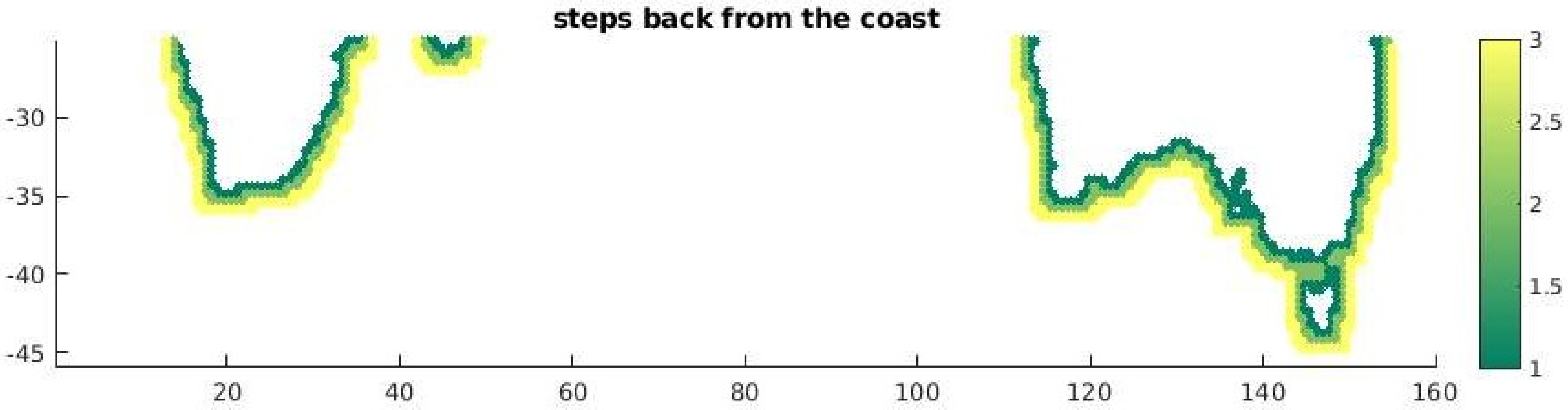


Division in domains from Alves, 2006 (https://doi.org/10.1016/j.ocemod.2004.11.007)

Interested in extremes generated by extra-tropical cyclones, which have strong seasonal variation.

Data Selection

Coastal accuracy of global models



How near to the coast do these data become 'representative' of offshore conditions, and at what depth and distance from the coast, global models are no longer usable?

We do a sensitivity test to proximity to coast with the multidecadal ERA5 run. The results are a trade-off between getting 'near' to the coast, while not having the data corrupted by the land

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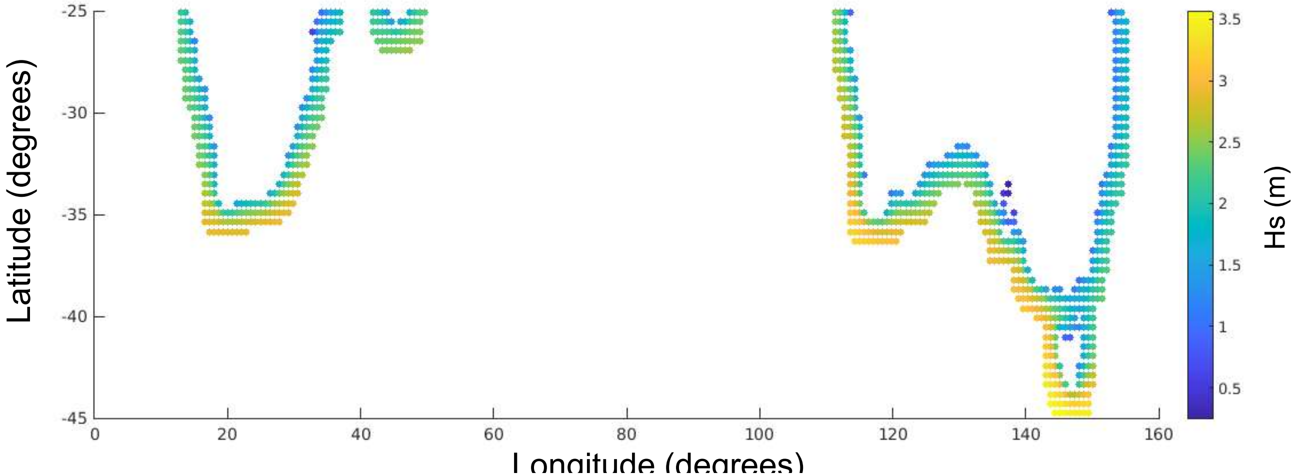
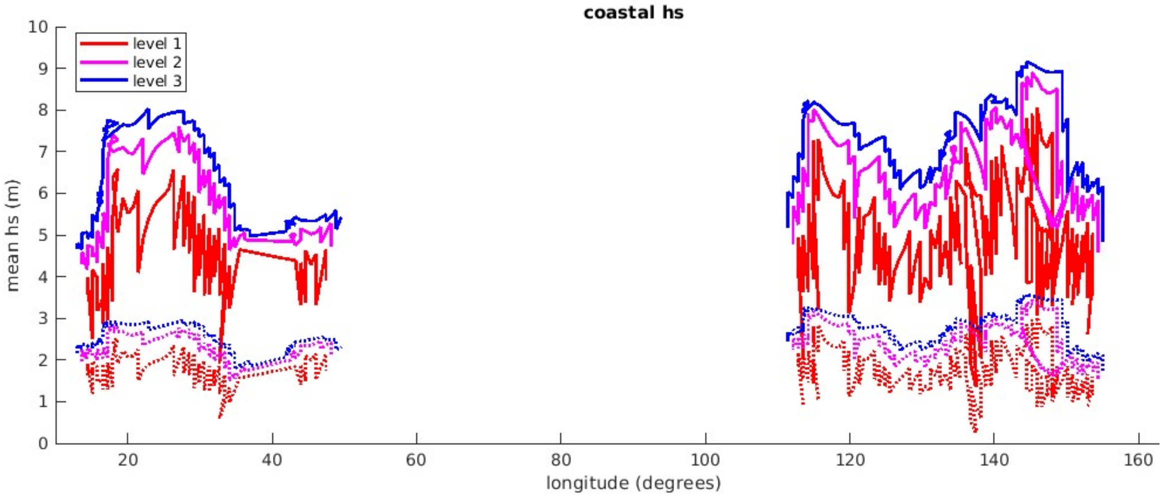
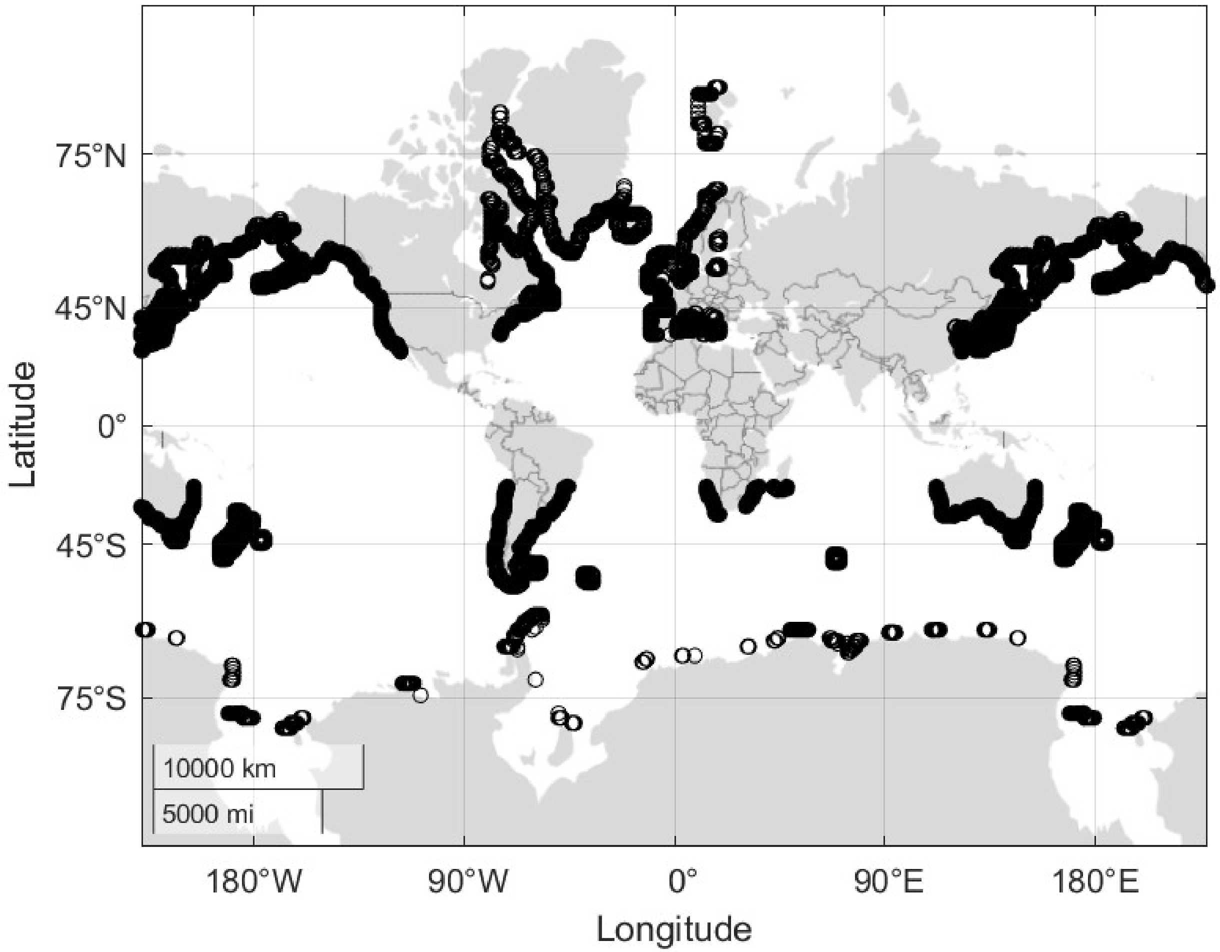
Data Selection





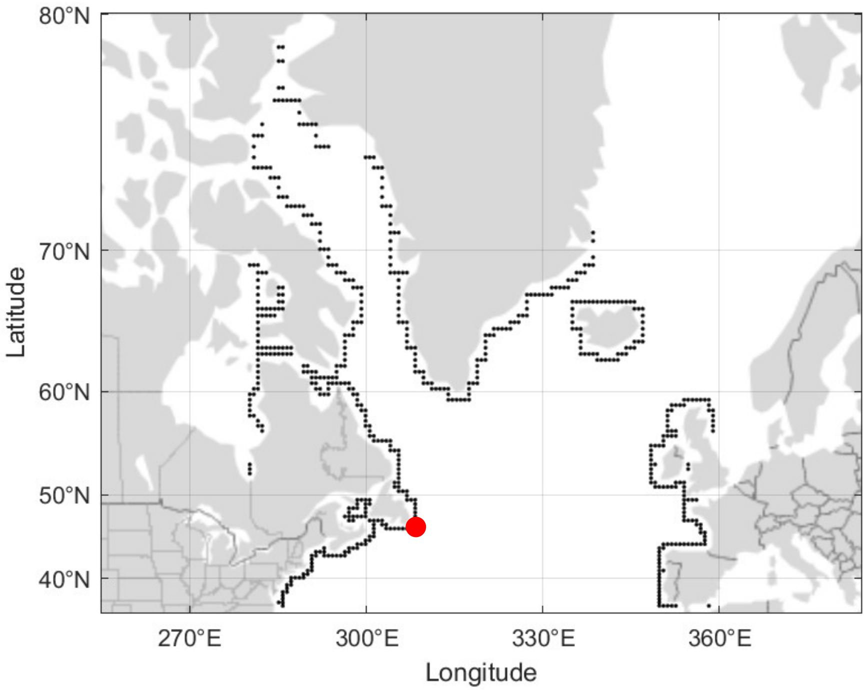
Very close to the coast (1 grid box away) model results were found to be extremely noisy (missing coastal processes at the resolution of the global wave model).
2 steps back represents a more credible coastal wave climate, another step further we miss-out some details of coastal geometry, while not gaining any additional coherence of results. So ‘level 2’ was chosen as optimal dataset with which to analyse coastal wave trends

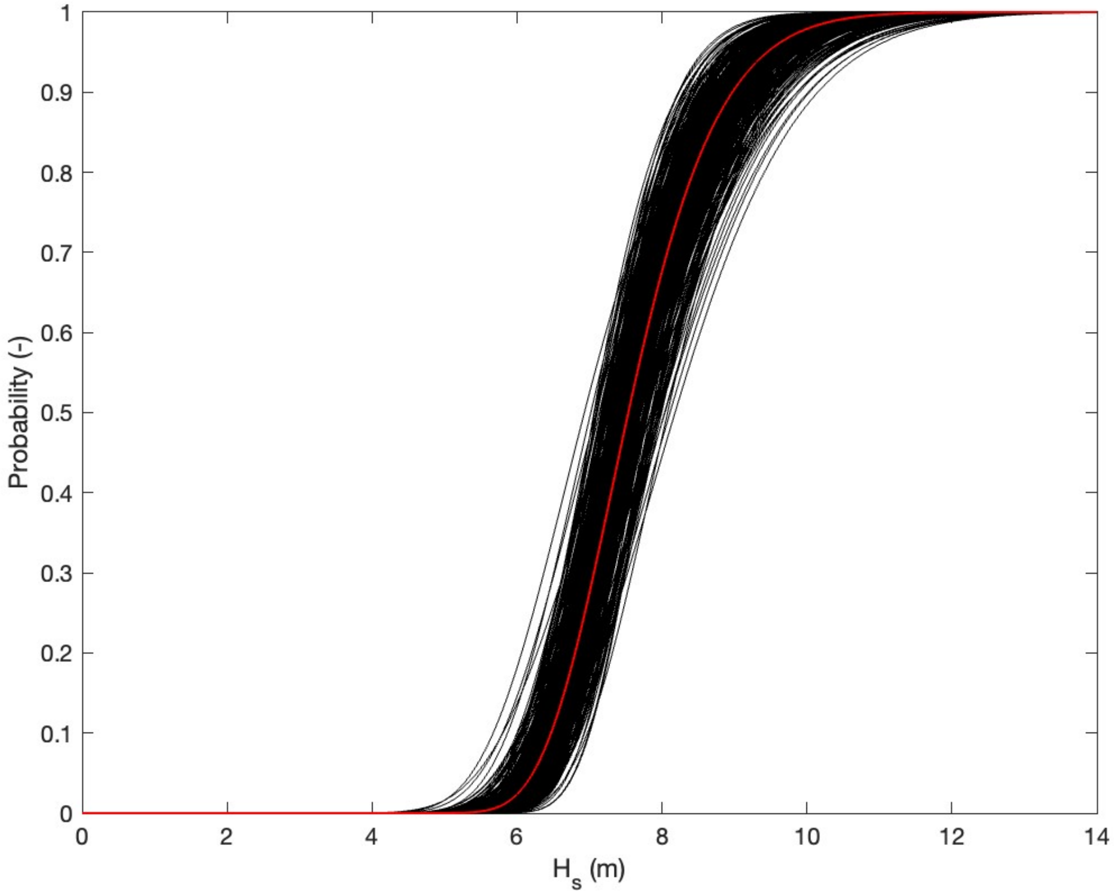
Data



75°N
45°N
0°
45°S
75°S
Latitude
10000 km
5000 mi
180°W
90°W
0°
90°E
180°E
Longitude

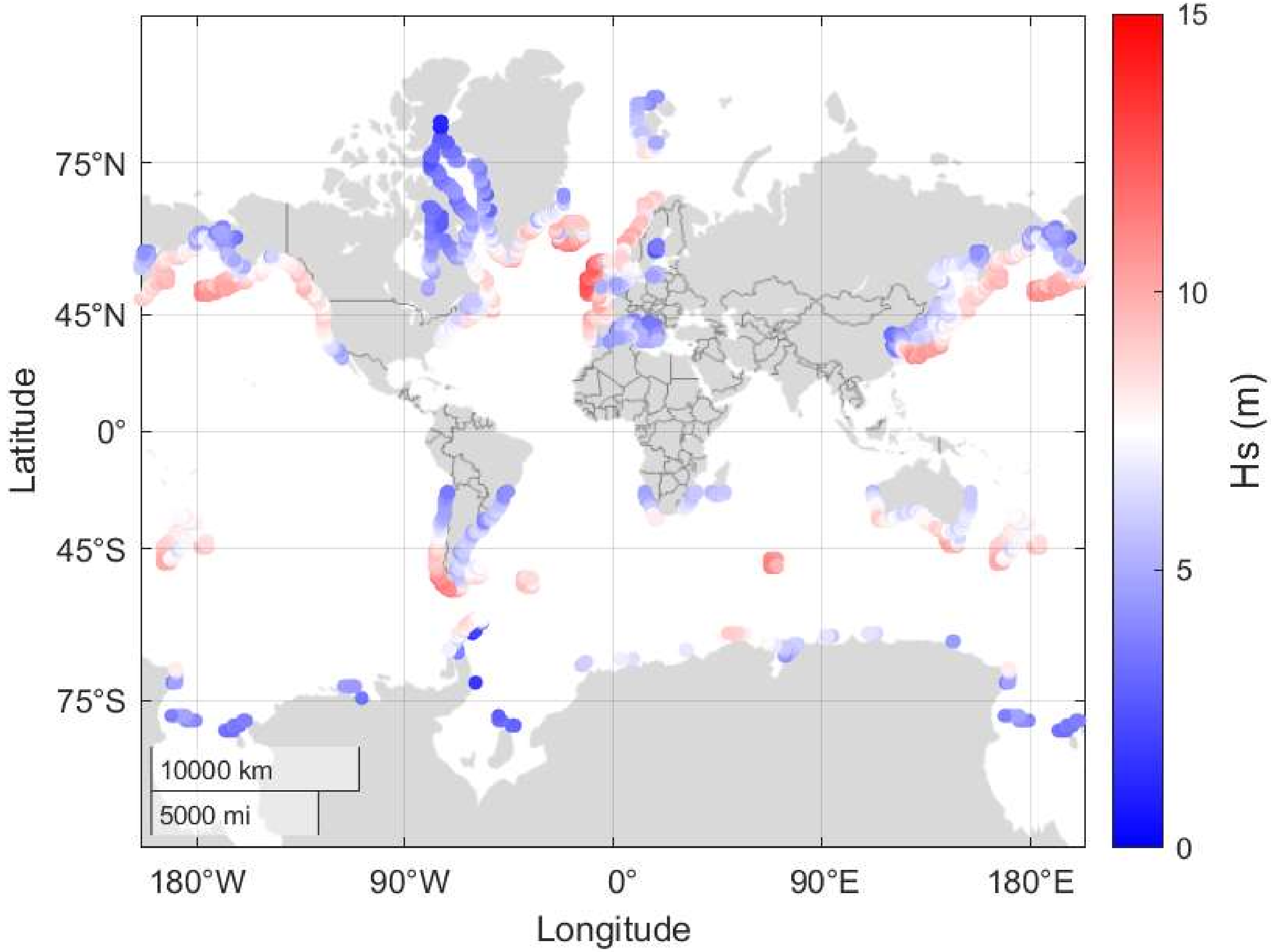
Results for example point



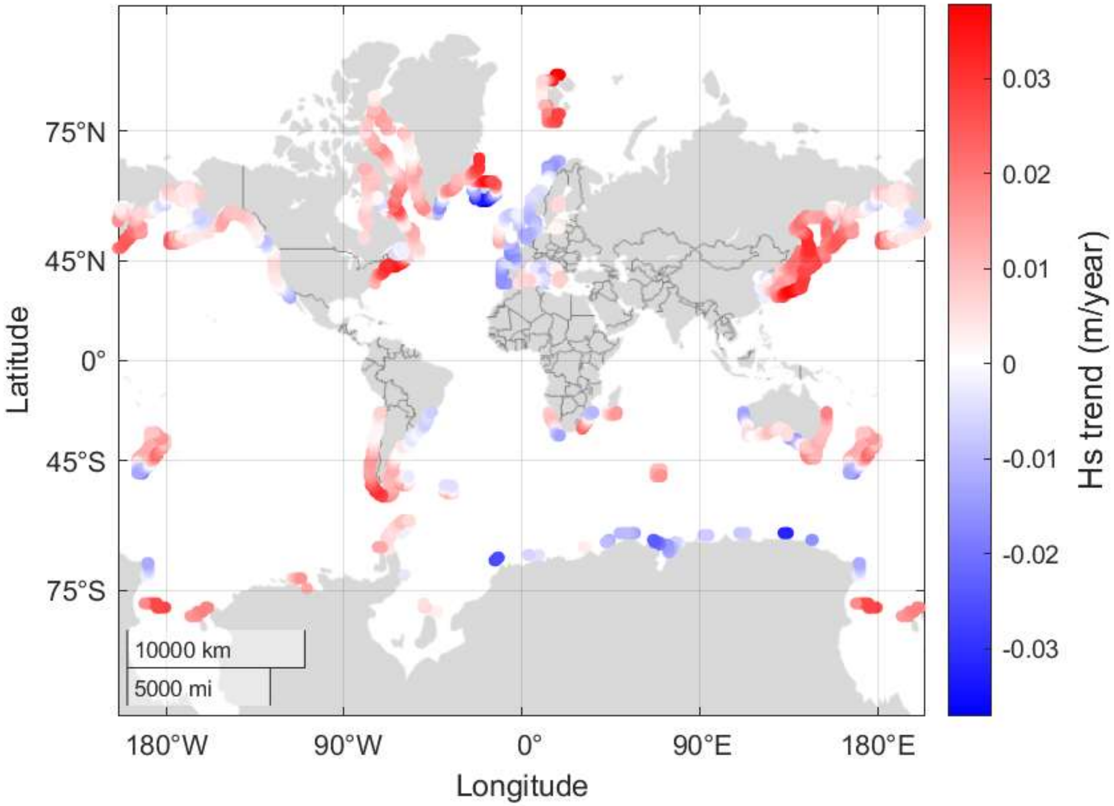


Results

Tr =10 years

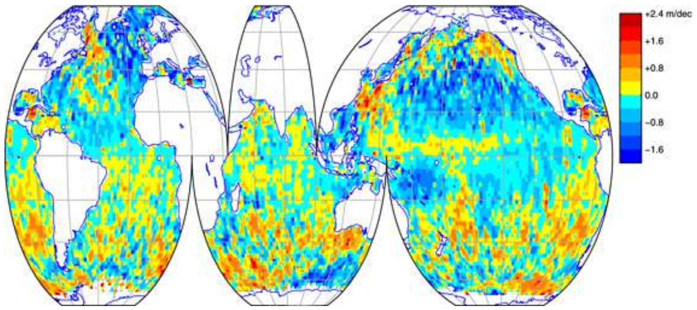


Trends

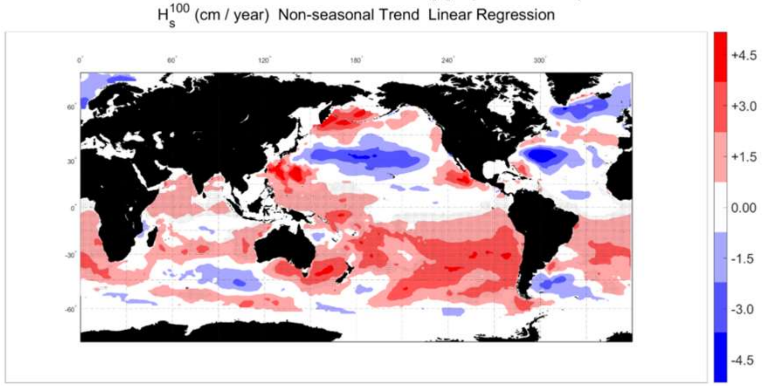


Tr =100 years

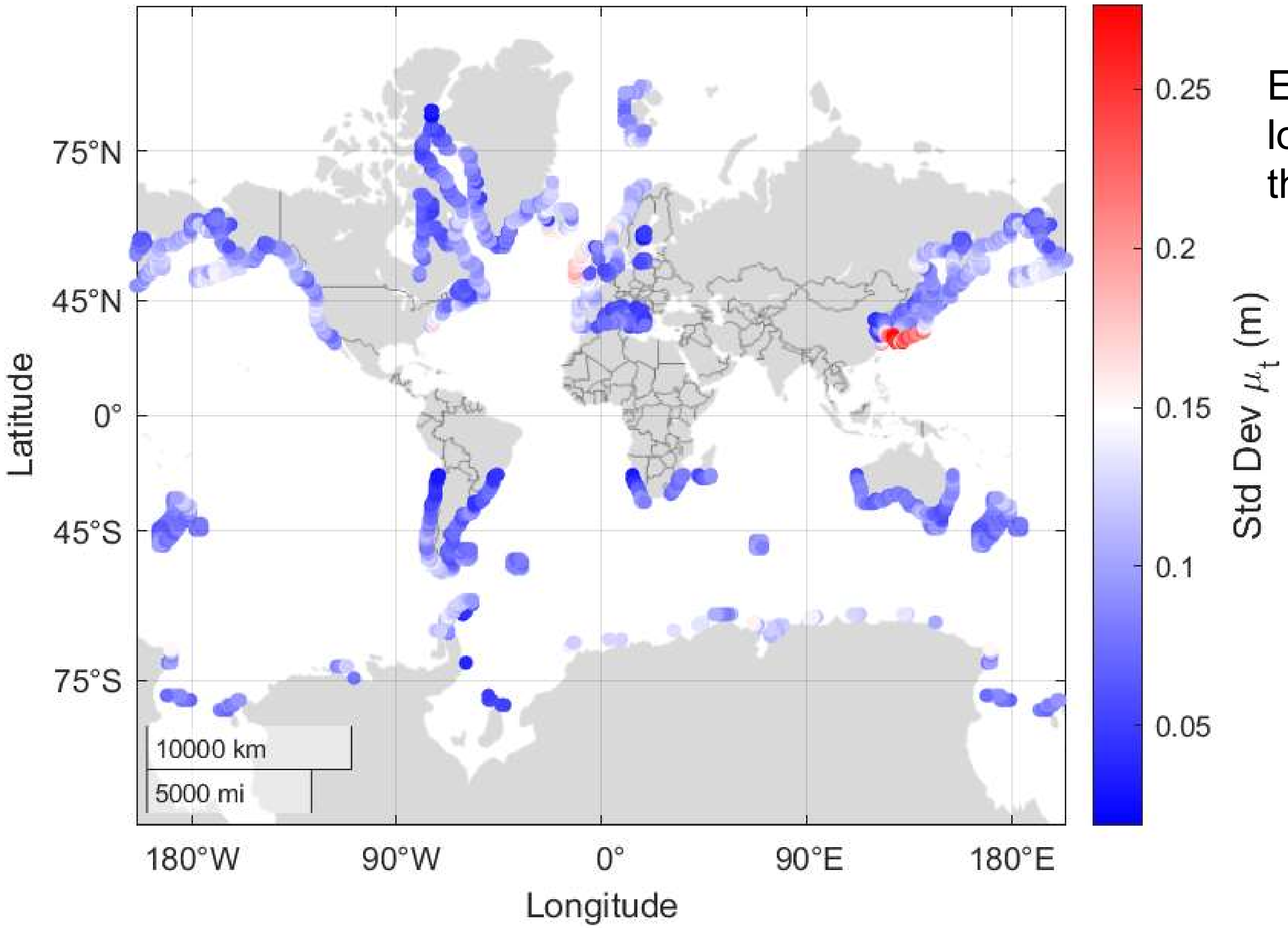
Trends for Hs with Tr= 100 years, compared with Young et al. (2012)



and Takbash and Young (2020)

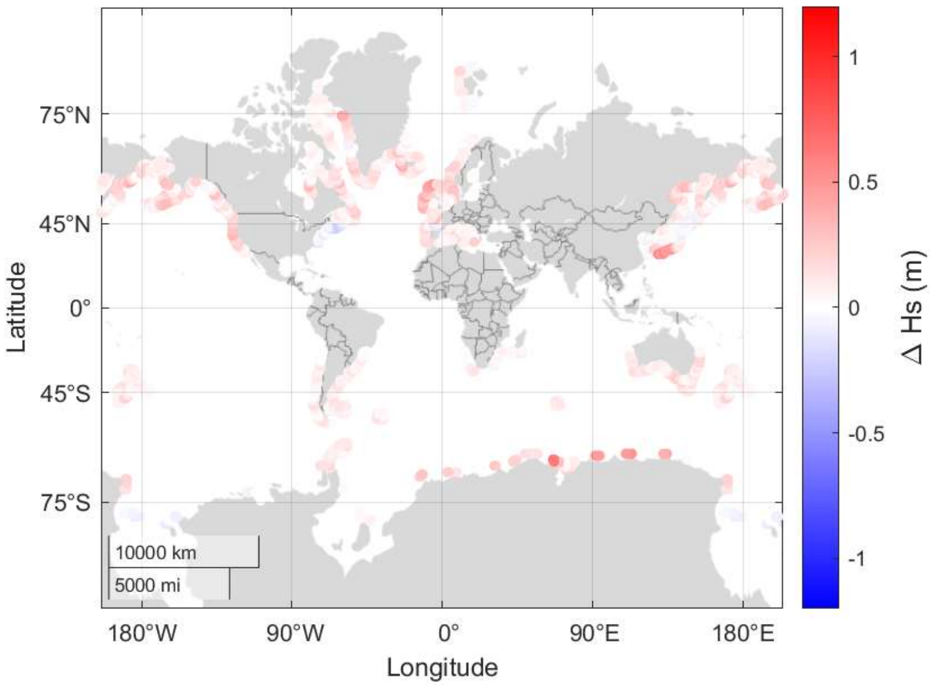


Uncertainty

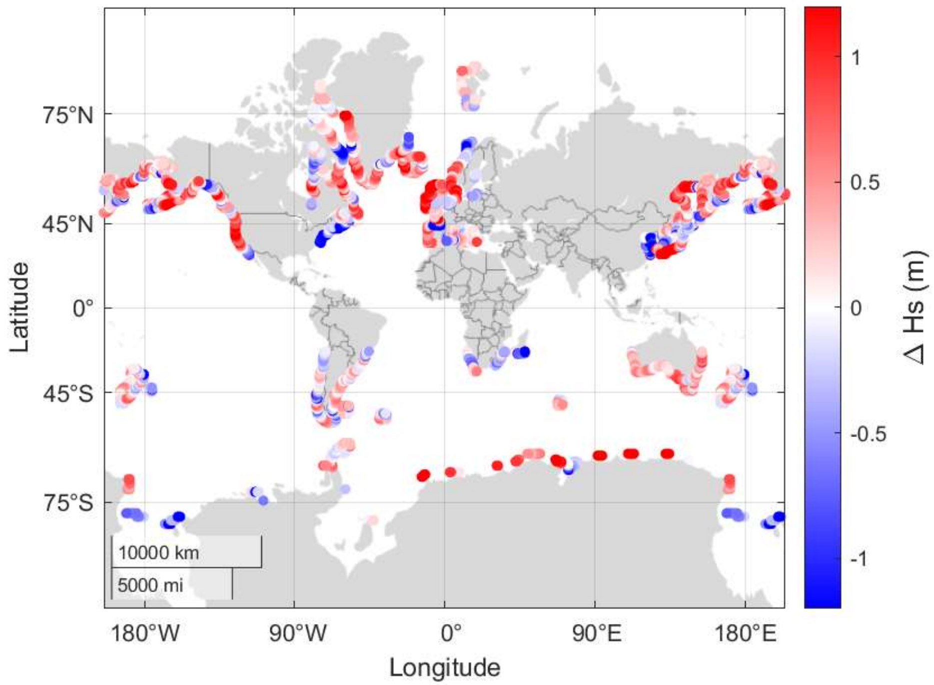


Example: standard Deviation of the GEV location parameter provides an indication of the uncertainty.

Comparison BHM and PBI

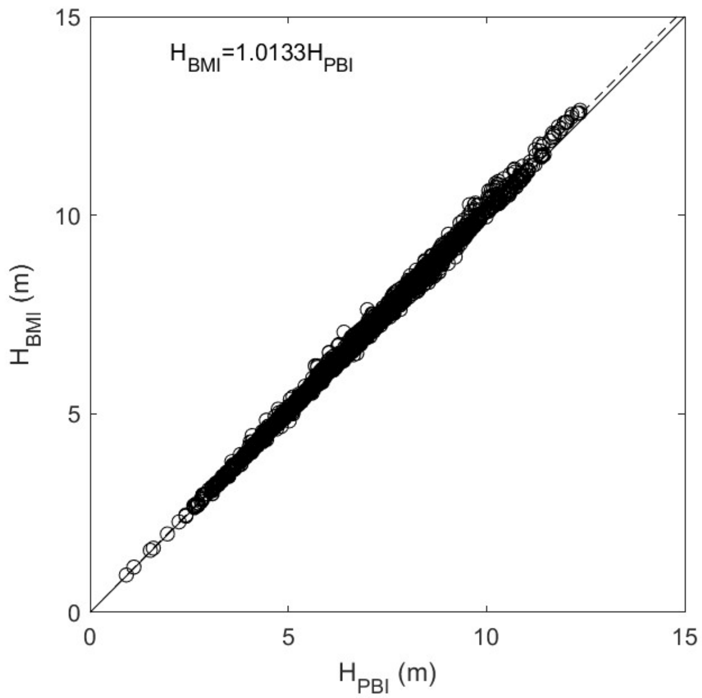


Tr =10 years

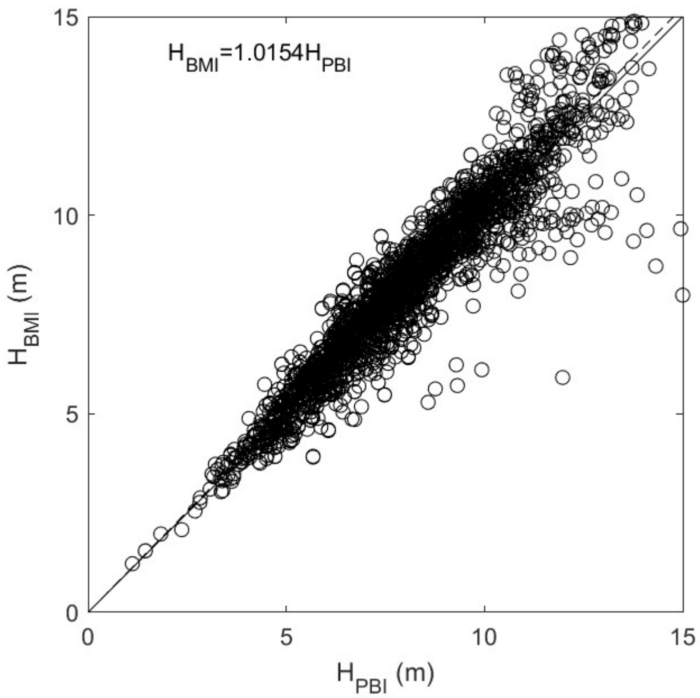


Tr =100 years

Comparison BHM and PBI



Tr =10 years



Tr =100 years

Conclusions

- We used the BHM from (BAYEX, Calafat 2024) to analyse significant wave height extremes globally.

-A methodology to extract coastal data from global models, applied to the ERA5 dataset for extra tropical areas was developed.

-Trends emerging from ERA 5 are consistent with literature ones for some domains (e.g. North Pacific and East coast of North America), however they diverge for others (e.g. European Atlantic Coast).

-The method provides slightly more conservative estimates of return levels, compared to point based inference.

Future Work

-Analyse future trends using projections

-Integrate this approach with existing extreme value analysis methods used in industry.