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Assessing Future Compound Coastal Flooding Along the Pacific Coast of North America Using Multi-model Projections

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ABSTRACT

Compound coastal flooding from storm surge and waves is a growing risk along the Pacific coast of North America, yet changes in their dependence under climate change remain unclear. Using multi-model projections (2006–2100, RCP8.5), extreme events were extracted via a Peak-Over-Threshold approach and analysed using Kendall's tau and copula-based joint return periods. Results show a strengthening surge–wave dependence across Alaska, British Columbia, and the western U.S. coast, leading to reduced joint return periods and more frequent compound flooding events. These findings highlight the importance of incorporating evolving multivariate dependence into coastal risk assessments to avoid underestimating future flood hazards.

Keywords: Compound coastal flooding, Wave–surge interaction, Climate change projections, Copula modelling, Peak-Over-Threshold (POT)

1 INTRODUCTION

Coastal flooding is one of the most frequent and costly natural hazards worldwide, with risk increasing as populations and infrastructure concentrate in low-lying coastal zones and the climate change intensifies extreme events. Flooding is often driven by the combined influence of storm surge, waves, and precipitation occurring simultaneously or in close sequence, producing compound events whose impacts exceed those estimated from single-driver or independence-based assumptions. Along energetic Pacific coastlines, wave–storm surge interactions are particularly important, as large offshore wave fields associated with extratropical cyclones can coincide with elevated surge levels, enhancing coastal water levels through wave setup, runup, and overtopping. These processes strongly influence flood extent but are inadequately represented when wave and surge hazards are treated independently. The changes in wave–surge dependence can substantially alter compound flood probabilities and design exceedance risk. Despite recent advances in compound hazard research, significant gaps remain in understanding multivariate dependencies and their potential evolution under climate change, especially along the Canadian Pacific coastline where evidence is limited. Given projected changes in storm tracks, cyclone intensity, and wave climate in the Northeast Pacific, wave–surge dependence itself may evolve, with important implications for future coastal flood risk. This study examines how wave–storm surge dependence, may change under climate change, with a focus on impacts relevant to compound coastal flooding and adaptation planning.

2 DATA

Hourly time series for storm surge and significant wave height were extracted at 500 coastal nodes along the Pacific Ocean from 2006 to 2100. The dataset comprises TELEMAC model outputs forced by three Regional Climate Models (RCMs) with four realizations under the RCP8.5 emissions scenario by (Cousineau & Murphy, 2022). To support regional interpretation, nodes were grouped into four latitude-based zones: Alaska (54.49°–60.21° N), British Columbia (48.0°–54.5° N), Northwest (42.0°–48.0° N), and West (35.77°–42.0° N). For consistent temporal comparison, the analysis period was partitioned into four windows: Baseline (2006–2025), Near Future (2031–2060), Mid Future (2061–2080), and Far Future (2081–2099).

3 METHODOLOGY

We identified extreme events for each driver using a univariate Peak-Over-Threshold (POT) approach with a 95th-percentile threshold. We declustered the series and chose only the maximum value from each event, helping to ensure that the extracted extremes are independent. Compound events between two drivers were then constructed by pairing these event maxima within a ±1-day time window. We quantified interdependence of compound events using Kendall's tau and examined how this dependence varies across the defined analysis periods. For the marginal behaviour of each extreme series, we fitted a Generalized Pareto Distribution (GPD), consistent with the POT framework. Joint dependence was modelled using a suite of copula families; their goodness of fit was evaluated using the Cramér–von Mises test, and the best-performing copula at each node was selected based on the Akaike Information Criterion (AIC). Finally, we calculated the joint return period using AND scenario as shown in equation1.

$$T_{AND} = \frac{\mu}{P(X > x, Y > y)} = \frac{\mu}{1 - F_X(x) - F_Y(y) + C\big(F_X(x), F_Y(y)\big)} \tag{2}$$

We quantified natural variability in joint return periods by generating 1000 bootstrap-resampled present-day annual blocks and using these to construct a 95% confidence interval. Projected return period changes were considered robust when they fell outside this interval and at least three of four models agreed on the direction of change (Bevacqua et al, 2020).

4 RESULTS

The interdependence analysis indicates that Kendall's tau for surge–wave compound events increase over the 21st century in Alaska, British Columbia, and the West as is shown in figure 1. This strengthening of dependence indicates that extreme storm surges are increasingly likely to coincide with high-energy wave conditions, enhancing total coastal water levels through wave setup, runup, and overtopping processes. While the interactions between storm surge and precipitation are more variable, they remain important for understanding flood risks in certain areas. The multi model median return period change and significance of surge-wave compound events in figure 2 shows that the percentage of nodes with negative significant return period change is increasing in Alaska and West regions. This shift implies that compound surge–wave extremes are projected to occur more frequently, effectively shortening the recurrence interval of high-impact coastal flooding events. Together, these results highlight the need to incorporate evolving multivariate dependence into future coastal flood risk assessments and adaptation planning along the Canadian Pacific coast, as reliance on stationary or independence-based assumptions may substantially underestimate future flood frequency and design exceedance risks.

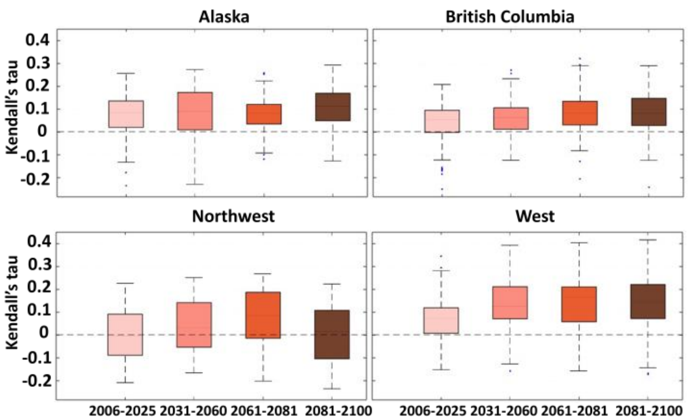

Figure 1. Multi model mean Kendall's tau of surge–wave events

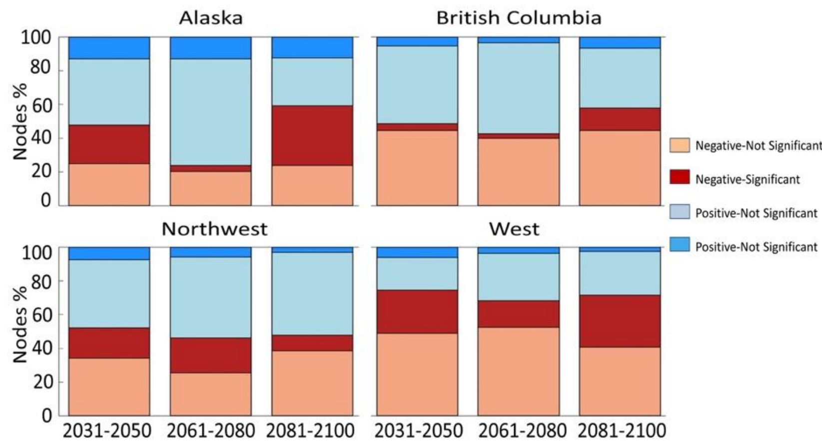

Figure 2. Multi model median return period change and significance of surge–wave events

5 CONCLUSION

Overall, our results suggest a strengthening dependence between storm surge and wave extremes and an increase in the frequency of compound surge–wave events along parts of the Pacific coastline, particularly in Alaska and the West. These changes imply that coastal flooding hazards may intensify not only because individual drivers become more extreme, but also because their joint occurrence becomes more likely under future climate conditions. This highlights the importance of moving beyond single-driver or stationary assumptions and adopting multivariate, climate-informed risk assessment frameworks that explicitly account for evolving dependence structures. Incorporating these dynamics into coastal planning, design standards, and adaptation strategies is critical to avoid underestimating future flood risk and to support more resilient coastal infrastructure and management decisions.

REFERENCES

1. Cousineau, Julien & Murphy, Enda. (2022). Numerical Investigation of Climate Change Effects on Storm Surges and Extreme Waves on Canada's Pacific Coast. Atmosphere. 13. 311. 10.3390/atmos13020311.

2. Bevacqua, E., Vousdoukas, M.I., Zappa, G. et al. More meteorological events that drive compound coastal flooding are projected under climate change. Commun Earth Environ 1, 47 (2020). https://doi.org/10.1038/s43247-020-00044-z