Earth & Space

Storm surge extremes are so SPATIAL

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By leveraging spatial coherence in storm surge extremes, we have been able to quantify the likelihood of extreme events occurring along European coastlines with high precision, even at locations without historical sea-level data.

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On hearing the term climate change, very often, what comes first to mind is rising temperatures, sea-level rise, or ice melting in Greenland and Antarctica. Only after catastrophic weather hazards, such as those associated with severe storms, the debate turns into the impact of climate change on extreme events. And the fact is that we will feel many of the most devastating impacts of climate change through changes in weather extremes. In particular, extreme sea-level events will become far more likely and intense during this century due to sea-level rise. This scenario will cause a dramatic increase in the risk of flooding along many coastlines throughout the world. Therefore, it is no surprise that substantial efforts in climate change adaptation are currently focused on the development of action plans that can reduce the increasing vulnerability of the densely populated and valuable coastal regions to these weather-related hazards. The emphasis of such plans is on cost-effective adaptation measures that aim to balance protection costs with the expected consequences of a hazard (e.g., flooding from a storm surge), were it to happen. A crucial ingredient for the success of such adaptation strategies is knowledge of extreme event probabilities: how often are sea-level events of a particular height expected to occur? In principle, we should be able to answer this question by looking into the history of extreme events. This, as it turns out, is no easy task. Traditional approaches to estimating event probabilities can only provide estimates at locations where tide gauge observations are available, and even at such locations, estimates are subject to large uncertainty due to the often small samples of extreme events. Our study presents a novel approach that overcomes these difficulties by taking advantage of spatial dependencies in sea-level extremes.

In simple terms, the property of spatial dependence, inherent to many geophysical processes, means that extremes at locations that are geographically close tend to exhibit similar attributes. This will manifest as locations sharing similar event probabilities and, if locations are close enough to be affected by the same events, also locations showing correlated extreme values.

We demonstrate that these spatial dependencies can be exploited to estimate both extreme surge levels and event probabilities at any arbitrary location, either gauged or ungauged, with reduced uncertainty compared to traditional approaches. A storm surge is a rise in sea level caused by the winds and low atmospheric pressure associated with a storm. The magic of our approach is a means of enabling the sharing of information across tide gauge sites. This leads to a probabilistic model wherein inferences about event probabilities at any specific site are informed not only by data at such site but also by data at all of the other sites according to their proximity and similarity. Rather than analyzing storm surge extreme events on a site-by-site basis, as the vast majority of studies to date have done, we analyze them by pooling all of the tide gauge data together through a spatiotemporal Bayesian hierarchical model that describes how the distribution of surge extremes varies in time and space.

Our study's key output is a probabilistic retrospective analysis of storm surge extremes that provides estimates of historical surge annual maxima and extreme event probabilities at any arbitrary location along the Atlantic and the North Sea coasts of Europe for the period 1960 through 2013. Importantly, the uncertainties associated with estimates of event probabilities in our reanalysis are up to a factor of three smaller than those in traditional site-by-site analyses. This reanalysis allows for a more accurate assessment of the risks posed by extreme storm surge events. It thus enables coastal planners to better protect coastal areas by implementing more cost-effective hazard mitigation plans. But observation-based estimates of event probabilities are not only essential for impact management purposes. Our reanalysis will also provide critical ground truth on which to judge climate model simulations of past extreme behaviour and aid current efforts towards understanding the link between extreme events and climate change. Furthermore, one could easily extend our Bayesian model of surge extremes to include other types of extremes. You could also incorporate response patterns associated with external climate drivers with a view of, for example, isolating the human contribution to changes in extremes.