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Can Small Islands Protect Nearby Coasts From Tsunamis? An Active Experimental Design Approach

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In recent years we have witnessed the dreadful damage tsunamis caused in coastal areas around the globe. In some of these locations, small islands in the vicinity of the mainland offer protection from wind-generated waves and thus communities were developed. But do these islands act as natural barriers to tsunamis? Recent post-tsunami survey data reveal that in certain cases the run-up in coastal areas behind small offshore islands was significantly higher than in neighboring locations. To study the conditions of this run-up amplification, we solve numerically the nonlinear shallow water equations. We use the simplified geometry of a conical island sitting on a flat bed in front of a uniform sloping beach. Hence, the experimental setup is controlled by five physical parameters, namely the island slope, the beach slope, the water depth, the distance between the island and the plane beach and the incoming wavelength, while the wave height was kept fixed. An active experimental design approach was adopted in order to find with the least number of simulations the maximum run-up amplification on the area of the beach behind the island with respect to a lateral location on the beach, not directly affected by the presence of the island. For this purpose, a statistical emulator was built to guide the selection of the query points in the input space and a stopping criterion was used to signal when no further simulations were needed. We have found that in all cases explored, the run-up amplification was larger than unity and in certain occasions reached up to 70% increase. The presence of the island delays the run-up of the wave on the plane beach behind it, while edge waves generated by the run-up in lateral locations on the beach converge towards the center. The synchronous arrival of the three waves (2 edge waves and tsunami from the lee side of the island) is responsible for the run-up amplification in these areas. The use of the active experimental design approach can result in a reduction of the computational cost up to 75%. This approach is not specific to tsunami modeling, but can be applied more generally to optimization problems of convex functions with cost restrictions. In addition, the emulator can be used to quickly predict the run-up amplification for a given set of input parameters, before the actual simulation is ran.