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Exploring the interplay of wave climate, vertical land motion, and rocky coast evolution

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The integration of wave energy imparted to sea cliffs and its conversion into erosion and mechanical work drives the evolution of rocky coasts. However, this near-shore transformation of wave energy remains poorly constrained.

We compare 4 cliff-top seismic records (Orkney Islands, UK; La Jolla, USA; Santa Cruz, USA; Boulby Cliffs, UK) to characterize the response of sea cliffs to the prevailing wave climate. Across all sites, ground displacement scales with wave height and decays with distance from the cliff, but with varying degrees of sensitivity. 3 of 4 sites behave in a mechanically consistent manner - only showing modest increases in ground shaking. Further, decay in displacement at these 3 sites is consistent with energy loss due entirely to geometric spreading of seismic waves. Near-shore wave modeling suggests that shore platform morphology at these sites has evolved to an equilibrium state, such that delivered cliff-face wave energy is roughly constant across the full range of wave conditions.

Ground displacement on Orkney is significantly more sensitive to changes in wave height. Landward energy loss at Orkney is also more pronounced, potentially a signature of active rock damage processes. This increased sensitivity suggests that the near-shore has not yet evolved to reflect the incident wave climate. Indeed, wave breaking on Orkney is concentrated at the cliff face. As such, the transfer of wave energy is more efficient, resulting in wave energy flux orders of magnitude larger, and more variable, than all other sites.

Vertical land motion on Orkney is 2x more rapid than all other sites. This more rapid vertical motion is likely to outpace cliff retreat and beveling of the shore platform. As such, the near near-shore cannot adjust to the incoming wave climate, and does not reach an equilibrium state. Instead, wave breaking remains pinned at the cliff face, enhancing wave energy transfer.

We compile vertical land motion rates across the United Kingdom with coincident wave buoy data

and bathymetry. We find that for more rapid vertical land motion, wave breaking is concentrated at the coast in comparison with more distributed wave breaking at sites with more gradual vertical motion. We suggest that these differences in vertical land motion exert a first order control on the transfer of wave energy to rocky coasts, such that areas with rapid vertical land motion rates are (1) more susceptible to changes in wave climate and (2) remain in a prolonged transient state relative to the dominant wave climate.

These results have implications both for the processes and timescales governing the long-term evolution of rocky coasts, as well as for determining the susceptibility of modern coastlines to a changing wave climate.

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