Geophysical Research Abstracts
Vol. 19, EGU2017-2834, 2017
EGU General Assembly 2017

A predictive model of beach formation along a headland-dominated high-energy coastline

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Here we use a combination of empirical observation and numerical modelling to propose a fundamental relationship between the average offshore slope and the presence of a sandy beach in embayments in a high-energy, headland dominated coastline. We identify a threshold gradient of $\sim$0.025 (1/40) that marks a critical transition in beach formation under different climatic conditions. Analysis of global Admiralty chart data compiled by UKHO reveals an approximately 80% chance of finding a sandy beach in an embayment with an average offshore slope of less than 1/40, and less than 40% chance on a slope steeper than 1/40, with probabilities decreasing as slope increases.

Numerical modelling of idealised, meso-scale embayments using the MIKE21 sediment transport model indicates that beaches can form in embayments with a slope steeper than 1/40, but only in persistent calm conditions. Modelling also shows that if a beach with an offshore gradient steeper than 1/40 is removed by storm action within a period of persistent stormy conditions, it will not reform. Beaches located on embayments with shallower gradients than the 1/40 threshold can reform swiftly in both calm and stormy conditions. Increase entrainment time of sediments being transported nearshore during persistent stormy conditions inhibits the ability for beach material to accumulate, thus a stable beach cannot form.

Our findings have wide implications for both contemporary coastal engineering in the face of future global climate change and the interpretation of coastal archaeology spanning periods of quite different coastal storminess- such as the Medieval Climate Anomaly-Little Ice Age transition. This research offers a tool to predict the location of unstable beaches along these coastlines.