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Performance of a data-driven technique applied to changes in wave height and its effect on beach response

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Abstract

In this study the medium-term response of beach profiles was investigated at two sites: a gently sloping sandy beach and a steeper mixed sand and gravel beach. The former is the Duck site in North Carolina, on the east coast of the USA, which is exposed to Atlantic Ocean swells and storm waves, and the latter is the Milford-on-Sea site at Christchurch Bay, on the south coast of England, which is partially sheltered from Atlantic swells but has a directionally bimodal wave exposure. The data sets comprise detailed bathymetric surveys of beach profiles covering a period of more than 25 years for the Duck site and over 18 years for the Milford-on-Sea site. The structure of the data sets and the data-driven methods are described. Canonical correlation analysis (CCA) was used to find linkages between the wave characteristics and beach profiles. The sensitivity of the linkages was investigated by deploying a wave height threshold to filter out the smaller waves incrementally. The results of the analysis indicate that, for the gently sloping sandy beach, waves of all heights are important to the morphological response. For the mixed sand and gravel beach, filtering the smaller waves improves the statistical fit and it suggests that low-height waves do not play a primary role in the medium-term morphological response, which is primarily driven by the intermittent larger storm waves.

Keywords: Beach profile; Canonical correlation analysis; Data-driven technique; Empirical orthogonal function; Forecast; Statistical model; Wave height threshold

1. Introduction

Shorelines are changing due to construction and development, as part of strategic approaches to flood and coastal management and shoreline management plans. As a result, in recent years there has been a greater need for more robust methodologies for incorporating risk assessments within coastal engineering design. The anticipated changes in climate arising from a rise in global temperatures will change wave and water level conditions, affecting the susceptibility of coastlines and beaches (Sutherland and Gouldby, 2003). The stability of many coastlines and beaches depends on the characteristics of the area in which they are located. Taking this into account, there is a need to understand how coastlines, and, in particular, beaches, react during storms, and how beach profiles respond to sequences of waves and storms. Without this knowledge, it is extremely difficult to provide accurate assessments of how coastlines and beach profiles interact and how these interactions are likely to change over time. Furthermore, it is important that shoreline management plans include this information so that coastal managers are able to have confidence in predictions of beach behaviour. Such plans typically require possible morphological changes to be assessed over a period of up to 100 years into the future. This requirement is difficult to meet with current forecasting

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methods, and estimates are often determined in an ad hoc manner on a case by case basis. Process-based morphological models have been developed to estimate meso-scale coastal morphological changes, but are yet to be used as a routine part of coastal management. The process-based models have performed well for short-term predictions, but they encounter difficulties when applied to meso-scale cases. Not only are these models difficult to operate, they can also suffer from instability and require significant computing and data resources for medium- to long-term prediction. As a result, some of the broad morphological tendencies observed in practice are difficult to reproduce reliably (de Vriend et al., 1993; Pan et al., 2010).

This has encouraged the development of data-driven techniques that are based entirely on analysis and extrapolation of observations (Różyński, 2003; Haxel and Holman, 2004; Reeve et al., 2016). With the growing amount of observations available from coastal monitoring programs in the UK and elsewhere and with the development of more sophisticated statistical analysis techniques, data-driven methods offer an additional alternative to the traditional methods available for meso-scale prediction. The underlying argument for employing data-driven methods is as follows: Predicting beach morphology is difficult. Predicting the wave characteristics is also difficult but is being done on an almost routine basis for navigation, logistics, and coastal management applications. If we can establish a strong relationship between the wave characteristics and beach response from historical records, then we can use this relationship, together with forecasts of the wave characteristics, to create forecasts of beach morphology. The method should work if (a) a strong relationship can be established between some measurements of wave activity and beach response, and (b) the conditions experienced in the forecast period are statistically similar to those upon which the relationship has been determined. This leaves open the question of which measurements of wave activity and beach morphology will provide the best linkage.

One method that has proven to be very useful in this context is canonical correlation analysis (CCA). CCA belongs to the family of methods based on correlation techniques and measures the relationship between the observed values of two sets of variables. It has been used with measurements from the Field Research Facility (FRF) at the Duck site in North Carolina, USA, by Larson et al. (2000) to detect coherent patterns in the wave and beach profile data and then to use these to predict the beach profiles on the basis of the waves alone. The researchers used a parametric description of waves based on the wave height and wave energy, and found the best results with wave height. Horrillo-Caraballo and Reeve (2008) extended this study to investigate how the choice of distribution function used to describe the wave height can influence the quality of predictions. Różyński (2003) used CCA to evaluate the evolution patterns of multiple longshore bars and the interactions between them in Lubiatowo, Poland. The sensitivity of the method to the data sampling rate and the duration of the records were investigated by Horrillo-Caraballo and Reeve (2010). They analysed the quality of forecasts made using CCA for beaches at Duck, USA and Milford-on-Sea, UK. They concluded that there is no strong reduction in prediction accuracy over the forecast period and that there is an increase in the forecast error when the duration and density of the records used to determine the regression matrix are degraded. Reeve and Horrillo-Caraballo (2014) used data-driven methods to forecast the behaviour of beaches with different exposures caused by nearby structures. They found that CCA could obtain strong correlation between the local beach behaviour and the offshore wave conditions, thereby encapsulating the effects of diffraction on beach evolution. This study extended that investigation to examine the sensitivity of the relationship between the wave height and beach response by invoking a graduated threshold for the wave height.

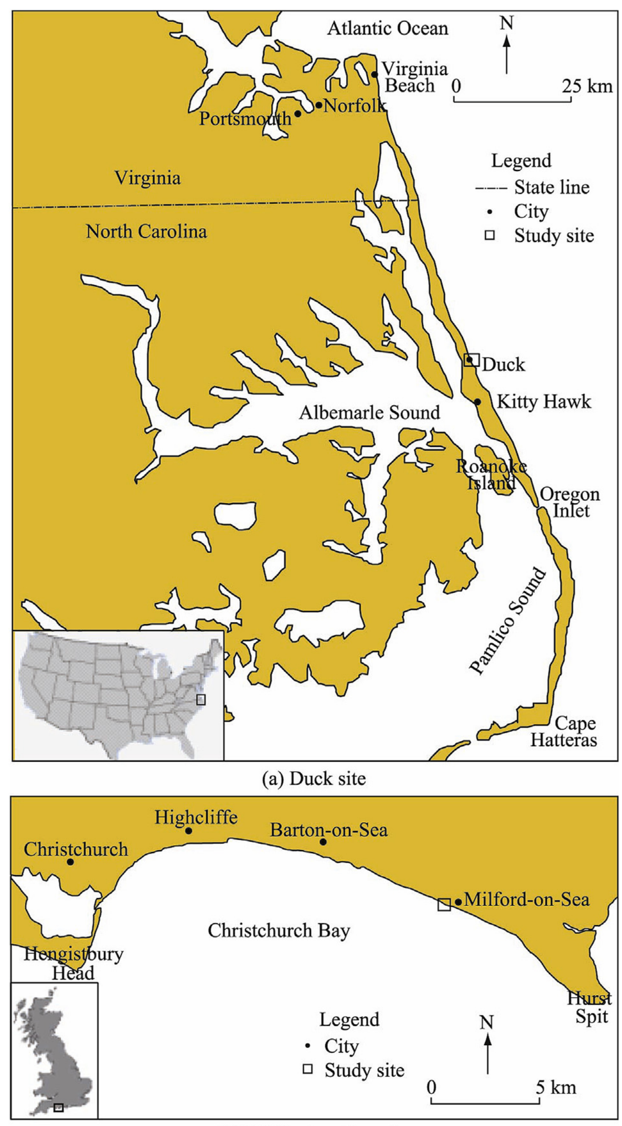

Fig. 1. Location of study sites.