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Using an artificial neural network to model seasonal changes in beach profiles

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ABSTRACT

An artificial neural network (ANN) was applied to predict seasonal beach profile evolution at various locations along the Tremadoc Bay, eastern Irish Sea. The beach profile variations in 19 stations for a period of about 7 years were studied using ANN. The model results were compared with field data. The most critical part of constructing ANN was the selection of minimum effective input data and the choice of proper activation function. Accordingly, some numerical techniques such as principal component analysis and correlation analysis were employed to detect the proper dataset. The geometric properties of the beach, wind data, local wave climate, and the corresponding beach level changes were fed to a feedforward backpropagation ANN. The performance of less than 0.0007 (mean square error) was achieved. The trained ANN model results had very good agreement with the beach profile surveys for the test data. Results of this study show that ANN can predict seasonal beach profile changes effectively, and the ANN results are generally more accurate when compared with computationally expensive mathematical model of the same study region. The ANN model results can be improved by the addition of more data, but the applicability of this method is limited to the range of the training data.

1. Introduction

The response of a beach to the natural environment is a challenging problem in the study of coastal morphology. The prediction of beach profile evolution under the action of waves and currents is one of the most important tasks in coastal engineering. Various factors such as wind and wave climates, the angle and the slope of the beach, tidal level, sediment grain size, storm frequency and the geology of the region can affect the formation and variation of beach profiles. The relationship between the beach profile changes and other forcing parameters can be linear or non-linear (Gunawardena et al., 2009), and generally depends on the temporal and spatial scale of the study area (Larson et al., 2000, 2003).

Different approaches are cited in the literature and by practicing engineers to predict variations in beach profiles caused by external driving forces (Gunawardena et al., 2009). Process-based mathematical and numerical models are one of the main approaches for the prediction of beach profile changes. Deterministic process-based models can either be relatively simple (e.g. observed offshore wave climate transformed to shallow water and applied to empirical sediment transport and continuity formulae) or can incorporate sophisticated two- or three-dimensional hydrodynamic models to calculate the hydrodynamics and morphological response over relatively large areas (Neill et al., 2008). Using numerical modeling, several models can be developed and linked to study beach profile changes on a variety of timescales. A wave model, tidal current model, sediment transport model (alongshore and cross-shore transport) and finally a morphological model should be developed, validated using field data and linked to each other for a specific study site. By employing this technique, significant progress has been achieved in the prediction of beach level changes (Neill et al., 2008; Ranasinghe et al., 2004). However, such techniques require considerable computational effort. In addition, there are still compelling discrepancies between model results and measured data (Neill et al., 2008). Uncertainties in understanding nearshore processes such as wave breaking, wave reflection, refraction, diffraction and longshore transport may be regarded as the main sources of error. In particular, the sediment transport, erosion and accretion rates along the shore are mostly estimated based on empirical formula and the physical mechanisms are not yet fully understood (Jones et al., 2007). Accordingly, other methods such as probabilistic models (Dong and Chen, 1999), wavelet models (e.g. Reeve et al., 2007), inverse models (Karunarathna et al., 2009) and data-based models have been introduced in this area.

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In data-based methods, by correlating past measurements of beach profiles with environmental forcings, it is possible to use black box models to predict beach profile response to future climate forcing. The beach profile data are collected using traditional survey techniques, video imagery, remote sensing (Kroon et al., 2007) and Differential Global Position System (DGPS). Various techniques such as non-linear complex empirical orthogonal functions (EOF), principal oscillation patterns (POP), singular spectrum analysis (SSA), canonical correlation analysis (CCA) and multichannel singular spectrum analysis (MSSA) have been applied in this regard (Reeve et al., 2007; Różyński, 2003).

Another branch of data-based models is Artificial Intelligence (AI). AI techniques are less expensive compared with physical-based numerical models and avoid the uncertainties involved in physical modeling. AI, in common with other data-based approaches, makes use of only the measured data, and is a practical tool which can be used to predict changes to the coastline as a response to changes in the forcing mechanisms. This tool is particularly useful in coastal application because many coastal engineers are interested in prediction (rather than deep understanding) of changes in the coastal zone as a response to changes in wave and tidal climates.

AI techniques such as artificial neural networks (ANNs) have been previously successfully applied to coastal studies (Chau, 2006), wave prediction (Lee et al., 2009; Kalra et al., 2005), ripple and beach bar behavior and location (Pape et al., 2007; Yan et al., 2008), coastal water level prediction (Huang et al., 2003; Ghorbani et al., 2010; Makarynska and Makarynskyy, 2008; Lee et al., 2007), wind–wave analysis (Browne et al., 2007; Herman et al., 2009), head–bay geometry (Iglesias et al., 2009), tidal prediction (Liang et al., 2008), break water design (Panizzo and Briganti, 2007; Yagci et al., 2005) and estimation of suspended sediment concentrations (Cipollini et al., 2001; Teodoro et al., 2007). The application of AI techniques such as neural network, fuzzy logic and genetic algorithm in predicting beach level change is a promising new branch of research. Although it has its own limitations (e.g. lack of physics and dependence on good quality training data), it can be examined in parallel with enhancing present physics-based numerical models. The performance of these two approaches against one another, in comparison with field data, can also be studied.

The purpose of this study is to investigate the potential of ANN to predict beach profile changes in a case study (Tremadoc Bay, eastern Irish Sea). The study region and in situ data are described in Section 2. An additional source of input data for the ANN, a wave model, is also explained in some detail in this section. The ANN model, including its input parameters and architecture, is introduced in Section 3. The model structure contains input vector, hidden layer, internal parameters, model training and evaluation, described in Section 4. Finally, the ANN results are presented and discussed in Section 5.

2. Study region and data sources

2.1. Study region

Tremadoc Bay is a shallow water bay (mean depth of order 10–20 m) located in the eastern Irish Sea (Fig. 1). The bay has semi-diurnal tides of range 4.5 m (spring) and 1.5 m (neap). Tidal currents in the bay are variable, with speeds of order 1–2 m s^{-1} in the region around St. Tudwal's Island and of order 0.1 m s^{-1} in the northeast of the bay (Neill et al., 2007). This latter region stratifies during the summer. Numerous sandy beaches are distributed along the Tremadoc Bay, interspersed by rocky promontories. Many of the beaches are popular for tourism and leisure activities, particularly those close to Pwllheli. The town of Pwllheli has a marina, and the entrance to the harbor has to be dredged annually due to sediment accumulation. This dredged material (of order 10×10^3 m^3 per year) is stockpiled and used for beach nourishment as required. The wave climate in Tremadoc Bay is generally from the southwest, relating to the dominant

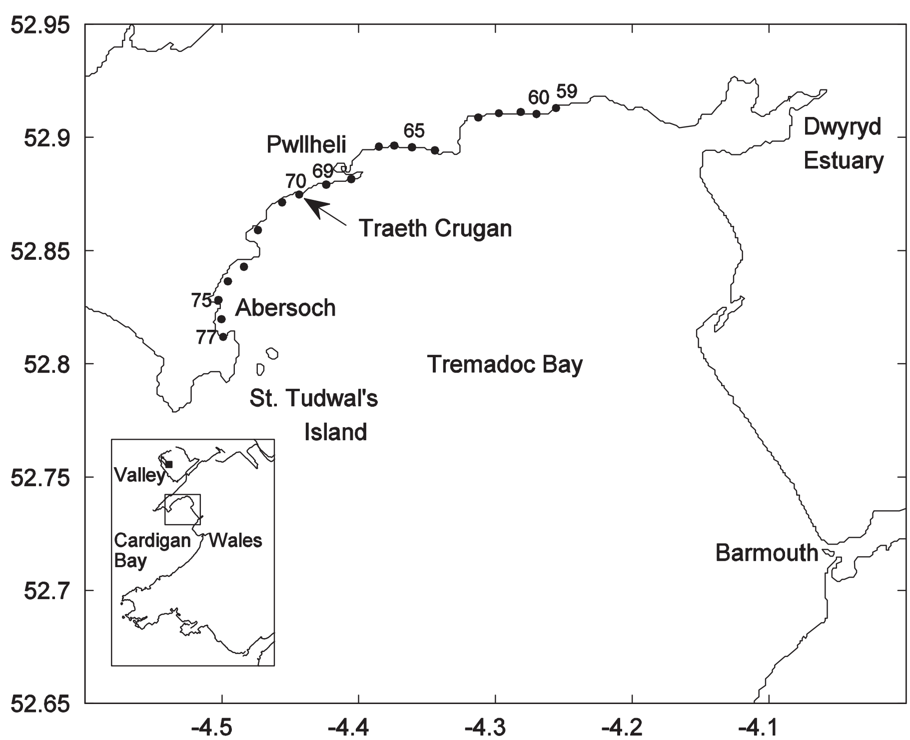

Fig. 1. Location of Tremadoc Bay and Traeth Crugan.