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Forecasts of seasonal to inter-annual beach change using a reduced physics beach profile model

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ABSTRACT

The observed seasonal to inter-annual variability of beach profiles has been investigated using a one dimensional beach profile model. The model used here is developed on the 'reduced-physics' modelling approach. The model uses a diffusion formulation as the governing equation and adopts an inverse modelling technique for solving the equation. The model is calibrated and validated against historic measurements of beach profiles at Hasaki Coast, located in the east coast of Japan. The beach is longshore uniform and characterised by a highly dynamic longshore bar-trough system. The model is then used to forecast seasonal to inter-annual scale beach change. The results are compared with beach change determined from measured beach profiles at Hasaki between 2007 and 2011. The simple modelling approach used yields encouraging results of seasonal to inter-annual scale beach change at Hasaki Coast.

1. Introduction

Beach change occurs as a result of complex interactions between beach morphology and a number of dynamic processes acting at a wide range of time and space scales. At time scales of a few hours to a few days, beaches change as a result of storms. Seasonal scale beach change occurs as a result of intra-annual variability of the incident wave climate resulting from local weather patterns. Inter-annual to decadal scale beach change can take place as a result of global climate variability or as a result of long term climate change.

As morphodynamic variability of beaches is directly linked to beach instability, coastal erosion, flooding and even breaching, it is important to be able to forecast beach change at timescales useful for making engineering and management decisions, with some confidence. However, as a result of the high levels of uncertainty involved in forecasting future hydrodynamic conditions and the limitations of existing modelling practice, forecasting beach change at time scales beyond several days with reasonable accuracy is extremely challenging and difficult.

Traditionally, empirical equilibrium models have been widely used for predicting beach change in the cross-shore direction. These include those due to Bruun (1954), Dean (1977, 1991) and Vellinga (1982). Even though these empirical formulae have a significant value when forecasting long term beach change, they have only a limited use in predicting beach change at short term time scales as they do not provide physical explanations of beach dynamics.

On the other hand, detailed process-based model modules (e.g. Reniers et al., 1995; Rolevink et al., 2009; Southgate and Nairn, 1993; Lesser et al., 2004) that combine hydrodynamics, sediment transport and morphodynamics provide useful insights into short term beach morphodynamics. They can be used to accurately simulate short term beach change. As a result, they are commonly used in assessing and predicting storm-driven beach change, which takes place at timescales of hours to days. Even though a few recent attempts have been made to use these models for making longer term forecasts (e.g. Pender and Karunarathna, 2013), uncertainties in hydrodynamic forcing, potential for over-sensitivity to initial and boundary conditions and computational intensity limit using them for predicting changes longer than a few days.

To make forecasts of seasonal to inter-annual scale beach change, which is most useful for coastal engineering and management purposes, some alternatives are required. Amongst those are 'reduced-physics' models which have been proposed in literature (e.g. Stive and de Vriend, 1995; Reeve and Fleming, 1997; Hanson et al., 2003; Karunarathna et al., 2008, 2009). In these models, governing equations are derived on physical arguments rather than from first principles. Their success depends on describing the key processes which are relevant to the timescale in question. As a result, they may not provide detailed process information of beach change (for example, storm-driven beach profile shape change) but give morphodynamic trends at timescales relevant to the processes retained in the governing

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equation. The application of these models to the problem of predicting beach profile change has shown significant promise (Karunarathna et al., 2012; Avdeev et al., 2009), despite the simplicity of this approach.

In this paper, we extend the Karunarathna et al. (2009) beach profile model to forecast seasonal to inter-annual scale cross-shore beach change. The model essentially takes a 'reduced-physics' approach, where beach change is considered to be primarily driven by 'diffusive' and 'non-diffusive' processes. Non-diffusive processes include any effects of waves, tides and other dynamic processes which contribute to beach change but we do not resolve these processes in detail. The model makes use of historic measurements of beach profile to 'calibrate' a few site-specific unknowns, similar to that of any process-based model application.

The aim of the paper is two-fold: (i) to evaluate the success of the modelling method when applied to a beach subjected to complex combination of environmental variables; and (ii) to forecast seasonal to inter-annual beach change, which will be useful to future coastal management planning. The paper is organised as follows: Section 2 gives a description of Hasaki Coast and measurements of beach profiles at Hazaki Observation Pier, which were used to calibrate the model. In Section 3, the model used to forecast inter-annual beach change is briefly described. Application of the model to Hasaki Coast and the results are presented and discussed in Section 4. Section 5 concludes the paper.

2. Hasaki Beach, Japan

Hasaki Coast is a longshore uniform, sandy coastline located in the Ibaraki Prefecture of Japan facing the South Pacific Ocean (Fig. 1). The beach consists of sediment with median diameter of 0.18 mm. Grain size remains almost uniform along the beach profile. The beach is subjected to both sea and swell waves. Tropical cyclones (typhoons) that occur during September–October generate high energy wave conditions along the Hasaki Coast. Relatively small waves occur from May to June. High wave conditions also occur between January and March as a result of extra-tropical cyclones. Based on the datum level at Hasaki (Tokyo Peil − 0.69 m), the high, mean and low water levels were recorded as 1.25 m, 0.65 m and −0.20 m respectively. Kuriyama et al. (2008) demonstrated that due to the micro-tidal environment and the high energy incident wave conditions, beach changes are primarily driven by incident wave conditions.

Deepwater waves at Hasaki Coast have been measured with an ultrasound wave gauge for 20 min every 2 h (Fig. 1). The water depth at wave measuring location is 24 m. Weekly beach profile surveys have been carried out at the Hazaki Oceanographical Research Station (HORS), initially at daily and subsequently at weekly intervals since 1986. The profiles have been surveyed at 5 m intervals along the observation pier, to the same datum level as that used for the tidal measurements. The measured beach profiles extend to an offshore distance of 497 m.

Weekly beach profile surveys between 1993 and 2010 were used in this study. Fig. 2 shows the envelope of beach profiles measured between 1993 and 2010 and the mean profile. Profiles measured between 1993 and 2007 were used for developing and calibrating the beach change model and profiles from 2007 to 2010 were used for model verification by comparison between predictions and observations.

The morphodynamics of Hasaki Coast is dominated by the nearshore bar-trough system. The beach profile variability of Hasaki Coast has been studied extensively. Using eight years of weekly measured beach profiles, Kuriyama (2002) studied the behaviour of nearshore bar-trough system and associated sediment transport using Principal Component Analysis (PCA). It was found that the bar is extremely dynamic and its development, migration and decay were caused by the spatial and temporal variations of cross-shore sediment transport. Kuriyama et al. (2008) investigated linkage between environmental factors and medium-term bar properties using 15 years of daily beach profile measurements along HORS pier. They used Complex Empirical Orthogonal Function (CEOF) analysis to investigate bar migration and found that the bar migration frequency was weakly correlated with the bar amplitude and offshore wave energy flux. A relationship between the shoreline variability of Hasaki Coast and the incident wave climate was studied by Kuriyama et al. (2012), using a simple shoreline model. They found that the Hasaki shoreline has a very strong inter-annual signature. They were also able to recognise numerous correlations between offshore wave climate at Hasaki and, the Arctic Oscillation index (AO); the Nino-West SST anomaly and the Southern Oscillation Index (SOI). The influence of climate change on the Hasaki Coast was

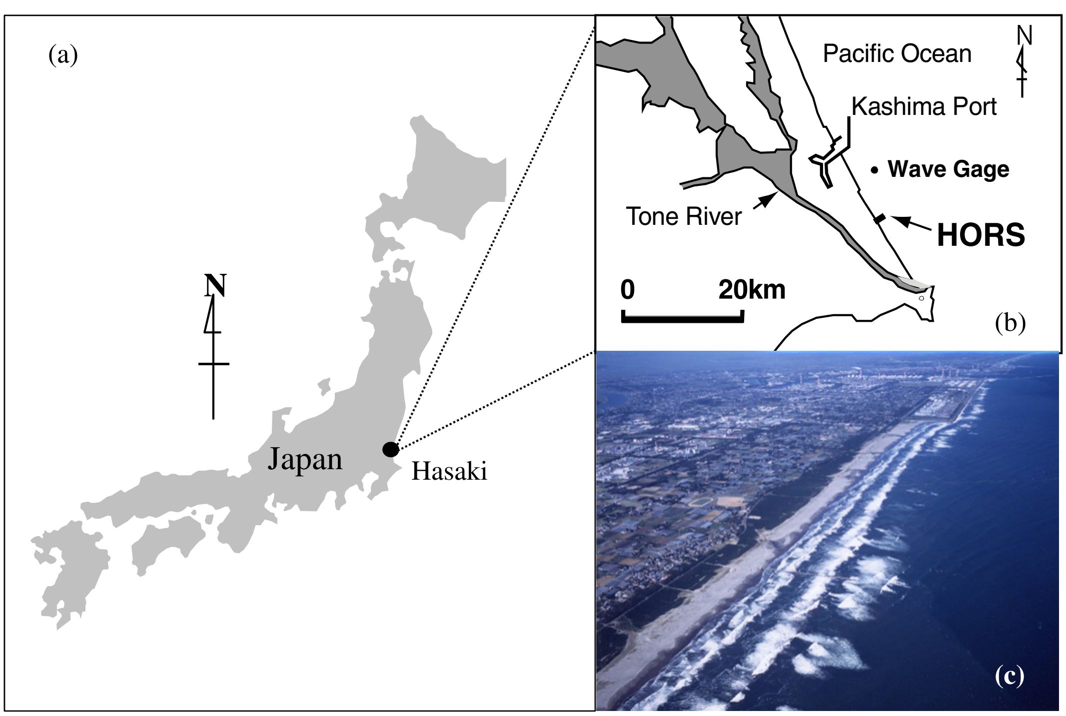

Fig. 1. Field Site at Hasaki, Japan. (a) Location of Hasaki Coast (b) Location of Hazaki Oceanographical Research Station and wave gauge and (c) view of Hasaki Beach.