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Multi-scale variability of beach profiles at Duck: A wavelet analysis

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Abstract

Beach profiles have been observed to change over a range of spatial and temporal scales; however techniques for quantifying this variability have not been fully established. In this paper, a wavelet technique is introduced as a method to study the multi-scale variability of beach profiles. The beach profile data comprising a 22-year time series surveyed at the US Army Corps of Civil Engineers Field Research Facility (FRF) at Duck are analysed using the adapted maximal overlap discrete wavelet transform (AMODWT). The analysis successfully identifies strong local features in the variability of beach profiles in time and space separately that cannot be isolated by traditional statistical methods. The analysis of spatial wavelet variances provides a new means of investigating the depth of closure. Analysis of variances by temporal scales shows that the combined effects of several temporal scales with one or two dominant scales can be seen at particular points across profiles whilst the dominant temporal scales are different at different portions of the profiles. The method allows for the extremely nonstationary behaviour of beach profile to be analysed into separate frequency bands that can facilitate the interpretation of morphological changes in terms of physical processes.

Keywords: Multi-scale; AMODWT; Local variation; Beach profile

1. Introduction

Beach behaviour in response to forcing processes or as a result of emergent phenomena is complex and highly non-linear. However, the traditional methods used to study the variability of beach profiles are mostly linear. Previous studies have employed techniques, such as the widely known empirical orthogonal function (EOF), principal oscillation patterns (POP), singular spectrum analysis (SSA) and canonical correlation analysis (CCA). These have contributed much to the analysis of variations in beach profiles. The above techniques have been discussed by Różyński (2003), Larson et al. (2003) and Southgate et al. (2003) in detail. Among these methods, the EOF technique is used perhaps most widely to study beach profile changes; the first such application of

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EOF analysis was presented by Winant et al. (1975). Recently, Southgate (1997), Southgate and Möller (2000), and Różyński et al. (2001) have discussed the self-organised responses of beach profiles, while Reeve (2002) commented on the potentially chaotic behaviour of coastal morphodynamics.

A growing body of observations, such as the data sets from the FRF at Duck, North Carolina USA and the Coastal Research Station (CRS) at Lubiatowo Poland in Europe, are now available. In parallel with this, new statistical techniques for identifying trends, quasi-periodic behaviour and other measures of predictability continue to be developed. Most recently, Różyński (2005) studied the long-term shoreline response at Lubiatowo using the multichannel singular spectrum analysis (MSSA).

The Duck data set is widely recognized as being of high quality and suitable for studying coastal changes over a range of scales in time and space. This is evidenced by the fact that previous researchers have studied a range of phenomena, although many of their studies have been based on the dataset covering 12 years from 1981 to 1992. Plant et al. (2002) discussed the interpolation of the data set considering the different bathymetric features. The response of beach profiles to wave/storm at Duck was investigated by Lee et al. (1995, 1998) and Larson et al. (2000). Lippmann et al. (1993) studied the episodic, nonstationary character of bar movement at Duck. Moreover, Stauble and Cialone (1996) focused on the sediment transport process affecting profile evolution at Duck.

The temporal scales of beach profile change at Duck were studied by Birkemeier and ASCE (1985), Larson and Kraus (1994), Capobianco et al. (1995), and Stive et al. (2002). Larson and Kraus (1994) discussed the depth of closure at Duck while Nicholls et al. (1998) examined the characteristics and interpretation of the depth of closure at Duck, as originally defined by Hallermeier (1981).

High spatial and temporal resolution data from Duck are suitable for analysing the long-term behaviour of beaches. The complex variability of the beach profile in space and time means that Fourier-type analysis is not always the most appropriate. This is because Fourier theory assumes that a signal is stationary and periodic in nature. EOF analysis, on the other hand, avoids any a priori assumption about the form of the variability, beyond the premise that the data are statistically stationary.

What is required is a technique that acknowledges the nonstationarity and intermittency of the forcing and behaviour of beach morphology. Thus, the purpose of this paper is to investigate the variability of beach profiles over a range of spatial and temporal scales, respectively using a technique that has been specially designed to treat nonstationary series. Here, we use a particular version of wavelet analysis known as the adapted maximal overlap discrete wavelet transform (AMODWT). The first concern in this paper is the locality of variation of beach profiles both in space and time. In addition, we try to identify the locations of discontinuous changes in spatial and temporal wavelet variances, which would be indicative of changes in the predominant morphodynamic processes, as opposed to gradual long-term trends. Subsequently, the new results are used to relate the changes identified in the spatial wavelet variances to extend the interpretations of Larson and Kraus (1994) and Nicholls et al. (1998) regarding the depth of closure of beach profiles.

2. Methodology

2.1. The wavelet transform

In this section, the wavelet transform is introduced. Some space is devoted to this as the wavelet transform has been used widely in disciplines where there is a need to examine intermittent or variable phenomena in long data series, such as in signal analysis (Mallat, 1989), geophysics (Kumar and Foufoula-Georgiou, 1994), earthquake analysis (Iyama and Kuwamura, 1999) and shock analysis (Smallwood, 1999). But wavelet analysis has only been used to a very limited extent in coastal engineering, and this is the first time to the authors' knowledge that it has been used for analysing beach morphology.

The most attractive property of wavelets is time (or space)-scale localisation so that the signal variance at a particular scale is related to a particular time (location). Another important property is that wavelets enable a multiresolution analysis to be performed, which partitions the variance of a signal according