Field observations and numerical modelling of wave energy dissipation over a north-west European saltmarsh

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Abstract
One of the key arguments made for coastal managed realignment has been the ability of mudflat and saltmarsh surfaces to act as a natural buffer zone, absorbing incident wave energy. However, the details of how, and how efficiently, this process takes place are poorly understood. This paper reports field measurements of wave processes across a cliffed mudflat – saltmarsh transition on the Dengie Peninsula, Essex, Greater Thames estuary, UK. It also considers how numerical wave models can be adapted to simulate the dissipative effect of the saltmarsh on wave climate. An example is given where the Collins friction coefficient in the SWAN (Simulating WAves Nearshore) model is adapted to account for dissipation over saltmarsh surfaces.

Introduction
Concerns over near-future sea level rise and possible increases in storminess, allied to the potential expense of replacing ageing coastal defences, has led to a deeper appraisal of how, and how efficiently, tidal mudflats and vegetated saltmarshes dissipate incident wave energy. This natural buffering function has engineering significance – in that flood defence embankments can be constructed to lower elevations where a significant width of fronting saltmarsh is present – and gives scientific legitimisation to the flood defence and habitat creation benefits of coastal 'managed realignment', whereby new defence lines are established at more landward positions, permitting tidal exchange, sedimentation and intertidal habitat development between old and new shoreline positions. Managed realignment has been widely adopted, and at increasing scales, across sites in NW Europe (e.g. Wolters *et al*., 2005), in spite of the lack of detailed, scientifically-based design rules to evaluate the optimal height, width, sediment type, vegetation and drainage conditions required to successfully create new areas of tidal wetland on artificially set-back coasts. In particular, little is known about the interactions between hydrodynamics, on the one hand, and, on the other hand, the nexus of sedimentation, surface topography and vegetation cover controls, even though these latter controls may significantly alter cross-shore wave energy distribution.

The following research involved collection of primary data on wave behaviour over a cliff-edged saltmarsh in Essex, southern North Sea coast, UK and built on understanding of the behaviour of this saltmarsh available from secondary datasets. The collated data was also used in order to create, calibrate and validate numerical wave models to simulate the dissipative effect of the vegetation and site topography on wave behaviour over saltmarshes.

Field Location

The Dengie marshes (Möller, 2006) lie between the estuaries of the Rivers Blackwater and Crouch/Roach, northern greater Thames estuary, southern North Sea. They form a narrow (< 100 – 700 m wide) band of saltmarsh, backed by reclaimed, seawall-protected agricultural land and fronted by extensive (up to 4 km) intertidal mudflats and sand bars. The coast is macro-tidal, with a mean spring tidal range of 4.8 m; the coast is also subject to periodic storm surges which may raise water levels 1 m or more above predicted tidal levels. Vegetation cover is typical of the floristically rich east coast marshes. There have been significant pulses of marsh advance and retreat over the last 150 years, although the dominant pattern over the last 50 years has been one of erosion; between 1955 and 1985, the central Dengie marshes narrowed by 1000 m. Rapidly eroding marsh fronts are characterised by cliffed transitions between marsh and tidal flat surfaces but elsewhere the marsh edge topography takes the form of a sloping ramp (Möller and Spencer, 2002).

Data Collection

Datasets on wave dissipation were collected on the ramped margin saltmarshes at Tillingham, northern Dengie marshes, between 1999 and 2001. An additional detailed hydrodynamic and geomorphological field monitoring campaign was undertaken between August 2003 and September 2004 focussing on processes over cliff edged saltmarshes at Bridgewick, southern Dengie marshes. Water levels and wave conditions were recorded using near-surface, horizontally-mounted pressure transmitters, in a methodology previously calibrated against video records of water level fluctuations (Moeller *et al.*, 1996). Low (1 Hz) and high (4 Hz) frequency measurements were triggered on sensor submergence and stored as i) 5 minute mean pressure (for derivation of tidal stage) and ii) continuous 4 Hz readings (for computation of wave spectra and summary statistics (including significant wave height; zero-upcrossing period and total wave energy). Full details of measurement, data storage and data processing methods are given in Möller and Spencer (2002). Cliff retreat was monitored through ground based surveying, kite aerial photography, ground based repeat photography and motion sensors emplaced in cliff fronts to record the exact timing of cliff failure.

Key observations

Significant wave heights (H_s) of between 0.07 m and 0.84 m were recorded in water depths of 1.73 m to 2.60 m on the fronting mudflat. Further analysis of the saltmarsh cliff dataset revealed that larger significant wave heights (greater than 0.32 m) were more rapidly dissipated by the cliff than smaller wave heights (less than 0.10 m) and that the rate of wave energy attenuation is affected by angle of wind influence, seasonality and wave height to water depth ratios. During the field campaign an average lateral retreat rate of 1.45 m per annum was recorded (with rates of up to 4.17 m per annum on exposed marsh cliff headlands); phases of substantial cliff retreat are linked to periods where high water does not fully inundate the marsh and wave energy is focussed upon the cliff face. However, retreat did not depend solely upon high wave energy events as other factors are involved, including high rainfall events enhancing geotechnical susceptibility to collapse.

Geotechnical investigations have shown that the Dengie marshes are composed of fine grained material which is less well consolidated, and has a lower un-drained shear strength, than marsh sediments at other sites in the UK. The Essex marshes have i) a high smectite content (which is water retentive and causes sediment swelling); ii) low calcium carbonate contents (<4% at Dengie; calcium is a divalent cation which aids clay flocculation processes) and iii) a high sodium absorption ratio (an important factor in influencing the degree of dispersive behaviour) (Crooks and Pye, 2000). All these characteristics are therefore likely to contribute to the rapid retreat of the marsh cliffs at Dengie and, behind the marsh edge, encourage internal marsh dissection.

In October 2003, the marsh experienced an algal bloom of *Ulva intestinalis* which brought to the site a large volume of shell deposits, of sufficient volume and extent to be visible features on aerial photography records of the site. The shell deposits remained at the site for ten months during the field campaign and were finally removed in August 2004 in a series of events which also resulted in the erosion of creek systems, including the extension of creek lengths by 0.3 m. August 2004 is noted in Met Office records as a high temperature, stormy and high rainfall month (Met Office, 2004).

Photographic observation of the field site, both in view form capturing the seaward edge of the marsh, and in plan form from the air, revealed concentrated erosion of promontory areas, the role of tension fracturing in initialising rotational slips and other mass movements at the site, as well as the fundamental role of large scale desiccation fractures in providing sites for creek formation and expansion.

Numerical modelling of wave attenuation over saltmarsh surfaces

The Simulating WAves Nearshore (SWAN) model has been used within the Delft3D modelling system to numerically model waves in the nearshore environment (Booij *et al.* 1999); this project looked at its potential applicability to the saltmarsh environment. SWAN was adapted to include a representation of a vegetated surface by a modification of the Collins friction coefficient which is already included within the SWAN model. The inputted figure for the Collins friction coefficient to describe surface roughness was adapted to include an additional algorithm based on vegetation density, vegetation height and stem rigidity. The adapted friction coefficient was inputted into the SWAN model as a field across the model varying in space representing the vegetation type and density change across the saltmarsh within the tidal frame. Two empirical events plotted against modelled data are shown in Figure 1.

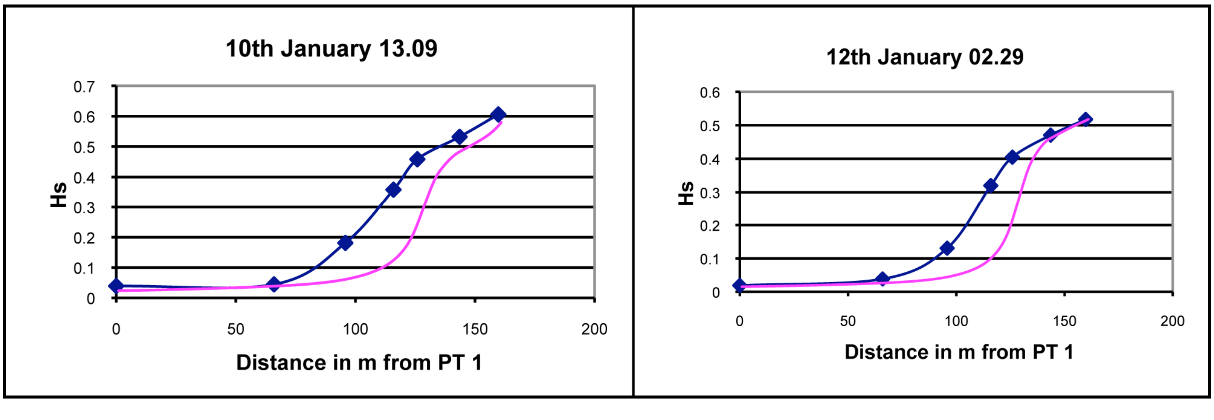

Figure 1 -Results of the model application to the Tillingham data set; dark lines on each of the graphs represent observed significant wave height values whilst the light lines represent those simulated by SWAN.

Conclusions

Field results, and the application of shallow water wave models to the field datasets, suggest that generic patterns of wave attenuation exist over ramped and cliffed marsh margins, but that site-by-site variation in marsh edge morphology, incident wave characteristics and surface roughness have significant effects on the wave transformation process.

Future research should focus on the role of geotechnical marsh sediment characteristics, the linkage of hydrodynamic thresholds to cliff erosion, as well as developing shallow water wave models that incorporate empirically quantifiable vegetation characteristics. A long-term and robust measuring programme is necessary for marshes subject to significant storm surges in order to measure the influence of saltmarsh topography and vegetation on hydrodynamic behaviour under extreme conditions.

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