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Assessment of beach and dune erosion and accretion using LiDAR: Impact of the stormy 2013–14 winter and longer term trends on the Sefton Coast, UK

Kenneth Pye [a,b,*], Simon J. Blott [a]

[a] Kenneth Pye Associates Ltd, Blythe Valley Innovation Centre, Blythe Valley Park, Solihull, West Midlands B90 8AJ, UK
[b] Engineering and the Environment, University of Southampton, Highfield, Southampton SO17 1BJ, UK

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ABSTRACT

An important question for coastal management concerns the importance of individual storms and clusters of storms on longer term beach sediment budgets, beach and dune erosion, and coastal flood risk. Between October 2013 and March 2014 a series of deep Atlantic low pressure systems crossed the Northeast Atlantic, and strong winds, high waves and high water levels affected many coastal areas in the UK and other parts of western Europe. Net dune recession of up to 12.1 m occurred around Formby Point. On 5 December 2013 the highest water level ever recorded at Liverpool (6.22 m ODN) coincided with waves of H_s of 4.55 m and T_p of 9.3 s in Liverpool Bay. Wave trimming of the dune toe occurred along the entire length of the Sefton coast, but significant dune erosion occurred only where the upper beach (between the mean high water spring tide level and the dune toe) was <25 m wide. Sediment budget calculations based on LiDAR surveys in October 2013 and May 2014 indicated a net loss of 127×10^3 m^3 of sediment from the beach (above 0 m ODN) and a loss of 268×10^3 m^3 from the frontal dune system, mostly at Formby Point. However, some parts of the beach to the south of Formby Point gained sediment, indicating net north to south transport over the winter. When considered in a longer term context, the 2013–14 winter represents only a small perturbation on the longer-term coast trend of erosion at Formby Point and progradation to the north and south. Analysis of LiDAR data over a longer time period 1999–2014 indicated upper beach and dune sediment loss of 780×10^3 m^3 from the north-central part of Formby Point, with net gains of 806×10^3 m^3 and 2116×10^3 m^3 in areas to the north and south, respectively. This indicates a net onshore transport of 2142×10^3 m^3 from Liverpool Bay towards the coast between Birkdale and Altcar, with a further net total of 210×10^3 m^3 transported towards the shore between Altcar and Crosby. In view of the demonstrated value of airborne LiDAR surveys for the quantification of storm impacts and longer term coastal changes, it is recommended that such surveys should be undertaken before and after each winter storm period, covering the area between mean low water spring tide level and a line 200 m landward of the dune toe, of as a part of the regional coastal monitoring programme.

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1. Introduction

Coastal dune systems act as important defences against marine flooding in many parts of the world, and the factors which control dune erosion and over-washing have been the subject of investigation for more than 50 years (Edelman, 1968, 1972; Vellinga, 1982, 1986; van de Graaff, 1977, 1986; Pye and Neal, 1994; Sallenger, 2000; Ferreira, 2005; van Thiel de Vries et al., 2008, van Thiel de Vries, 2009; Esteves et al., 2009, 2012; Splinter and Palmsten, 2012; Houser, 2013; Splinter et al., 2014; Palmsten et al., 2014; Tatui et al., 2014; Swann et al., 2014; Dissanayake et al., 2014, 2015a, 2015b). However, important questions remain, including the relative importance of individual severe storms and storm clusters on longer term erosion rates, the nature of factors which govern dune recovery rates, and what morphological and sedimentological aspects of dune, beach and shallow subtidal systems should be monitored. Answers to these questions are required in order to quantify and predict the vulnerability of beach/dune systems to storm events on different timescales, and the magnitude/rate/form of likely recovery. The purpose of this paper is to consider these questions in the context of the Sefton coast in northwest England.

The winter of 2013–14 in northwest Europe was unusually stormy and resulted in widespread coastal erosion and flooding. Between late October 2013 and late March 2014 several deep Atlantic low pressure systems, driven by a powerful jet stream, crossed the region, resulting

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* Corresponding author at: Kenneth Pye Associates Ltd, Blythe Valley Innovation Centre, Blythe Valley Park, Solihull, West Midlands B90 8AJ, UK.
E-mail address: k.pye@kpal.co.uk (K. Pye).

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in strong winds, large waves and high water levels. The 'winter' of 2013–14, defined by the UK Met Office as the period between 1 December 2013 and 28 February 2014, was the wettest in the UK since records began in 1910, and reanalysis pressure datasets suggest it was the stormiest for at least 20 years (Kendon and McCarthy, 2015), and possibly the last 143 years (Matthews et al., 2014). However, in terms of coastal processes and beach/dune morphological response it is more informative to consider the 'winter' as including the period 1 October to 31 March, and to consider the months April to September as 'summer'. Although storms do occur between April and September, they are fewer and generally less severe, and beaches generally show a tendency for levels to recover following the 'winter' storms. For this reason this paper considers the effect of storms which occurred during the extended 'winter' period 1 October 2013 to 31 March 2014 on the Sefton coast in northwest England (Fig. 1).

2. Storms affecting the UK in the period 1 October 2013 to 31 March 2014

The first significant storm to affect the UK was the "St. Jude" storm, also known as "Cyclone Christian", "Burkhard" and other names, which affected northwest Europe on 27–28 October 2013. The depression was initiated from a wave front off the eastern seaboard of the United States on 26 October. The developing depression moved eastwards and received additional energy from the remnants of extra-tropical storm Lorenzo situated in the mid-Atlantic. This, and the effect of a strong jet stream, caused rapid deepening of the depression as it moved rapidly towards Europe. The depression took a relatively southerly track, affecting the English Channel coast and East Anglia most severely.

On 2–3 November 2013 a further storm severely impacted the coasts of Devon and Cornwall, South Wales, Cardigan Bay and the eastern Irish Sea. Extensive damage was caused to the seafront at Aberystwyth in West Wales. An even larger storm event (named "Xaver" by The Free University of Berlin) affected the UK and mainland Europe on 5–6 December 2015. A low pressure centre originated near Greenland on 4 December and tracked to the north of Scotland, deepening rapidly to 967 hPa as it moved towards southern Norway and Sweden. The low pressure and strong northwesterly winds caused significant storm surges in northwest England and North Wales, along the east coast of Britain, and on the coasts of Germany and The Netherlands. Across Scotland winds gusted to 60–70 kn (111–130 km/h) and sustained winds reached hurricane force in the northern North Sea (Sibley et al., 2015). At Immingham, on the east coast of England, the observed high water level of 5.22 m above Ordnance Datum Newlyn (ODN) was higher than that experienced during the major storm surge event of 31 January

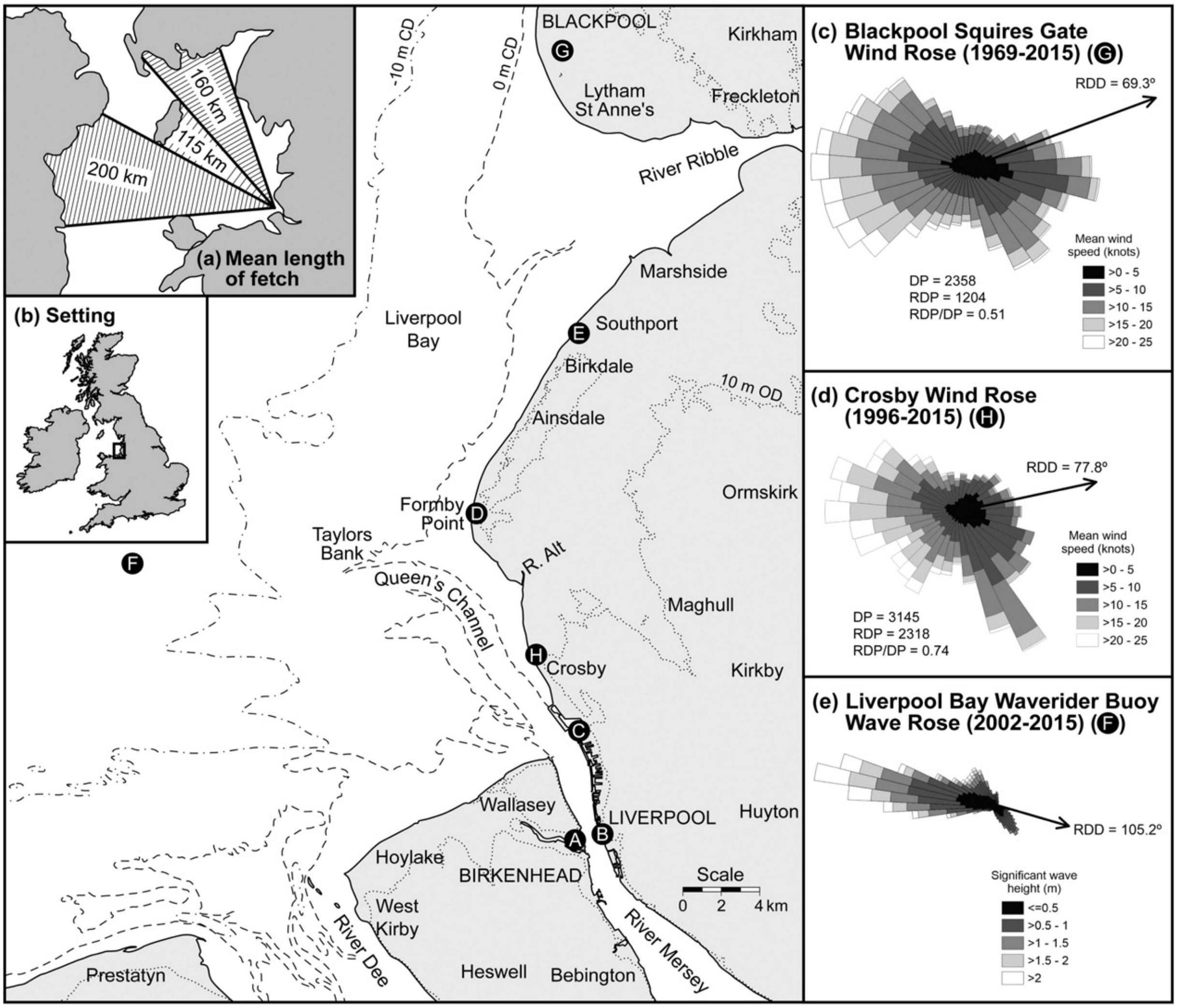

Fig. 1. Location map showing the main locations mentioned in the text. Letters indicate the locations of tide gauges (A = Alfred Dock, B = Princes Pier, C = Gladstone Dock), Secondary Ports referred to in Admiralty Tide Tables (D = Formby, E = Southport), wave buoy (F = Liverpool Bay WAVENET waverider buoy), and meteorological stations (G = Blackpool Squires Gate Airport, H = Maritime and Coastguard Agency, Hall Road, Crosby). Insets show: (a) mean lengths of fetch; (b) location of the Liverpool Bay within the UK, (c) wind rose for Blackpool Squires Gate Airport, with resultant drift direction (RDD) calculated using the formula of Fryberger and Dean (1979) for sand transporting winds >11 kn; (d) wind rose and RDD for Crosby; (e) wave rose for the Liverpool Bay wave buoy, with resultant direction for all waves scaled using wave power.

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