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Field measurements on spatial variations in aeolian sediment availability at the Sand Motor mega nourishment

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ABSTRACT

Spatial variations in aeolian sediment transport were measured at the Sand Motor mega nourishment in The Netherlands during a six week field campaign in the fall of 2014. A consistent significant increase in sediment transport in downwind direction (positive gradient) was measured over the intertidal beach area, indicating that the intertidal beach is a primary source of aeolian sediment, despite the high soil moisture contents. A small positive increase in transport in downwind direction was measured over the dry beach, indicating that local aeolian sediment supply was hampered. A consistent decrease in sediment transport in downwind direction (negative gradient) was measured at the transition between intertidal and dry beach, indicating local deposition of sediment. The negative gradients coincide with the berm edge and the onset of a shell pavement. Therefore deposition might be promoted by morphological feedback between a berm and the wind and the entrapment of sediment in the beach armor layer. The local sediment deposits cause the sediment supply to the dunes to be continued even during high water, resulting in a phased process. The influence of the beach armor layer reduces during storm events as the armor layer itself is being mobilized.

1. Introduction

The Sand Motor (or Sand Engine) is an innovative solution to counteract the anticipated coastal recession due to sea level rise (Stive et al., 2013). The Sand Motor is a 21Mm^3 mega nourishment along the Dutch coast that is constructed well above storm surge level and therefore largely shaped by wind. While the Sand Motor accommodates fetches up to 1.0 km and is permanently exposed to wind, the dry surface area is remarkably stable (Hoonhout and de Vries, 2016a). An armor layer consisting of shells, pebbles and cobbles prevent erosion by wind and thus limit the sediment availability (following the definition of Kocurek and Lancaster (1999)). Consequently, the aeolian sediment transport rates at the Sand Motor are limited to approximately 35% of the wind transport capacity (Hoonhout and de Vries, 2016a) making the Sand Motor an availability-limited coastal system.

In an availability-limited coastal system, not the wind transport capacity, but the sediment availability governs the sediment supply towards the dunes (Houser and Ellis, 2013). Sediment availability can be limited by various bed surface properties, like shells, salt crusts, moisture and vegetation. Studies on the influence of bed surface properties on aeolian sediment availability and transport started as wind tunnel experiments (e.g. Belly, 1964; Howard, 1977; Dyer, 1986; Gillette and Stockton, 1989). These studies typically determine an adapted threshold velocity that relates the theoretical wind transport capacity to a measured sediment transport capacity (Bagnold, 1937). In the field, the influence of different bed surface properties on sediment availability cannot easily be distinguished and the sediment availability is often presented spatially aggregated (Jackson and Nordstrom, 1998; Arens et al., 2001; Wiggs et al., 2004). The concept of critical fetch is a widely used approach for spatial aggregation of sediment supply (e.g. Jackson and Cooper, 1999; Davidson-Arnott et al., 2005; Davidson-Arnott et al., 2008; Bauer et al., 2009). The critical fetch is the distance over which the saltation cascade develops and aeolian sediment transport becomes saturated (Bauer and Davidson-Arnott, 2002). Since the saltation cascade develops slower when sediment is scarce, the critical fetch is inversely proportional to the sediment supply (Delgado-Fernandez, 2010).

Expressing the sediment supply in terms of critical fetch assumes that saturated transport is reached if the available fetch

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is sufficient. Hoonhout and de Vries (2016a) showed that sediment supply can be severely limited even with fetches as large as at the Sand Motor. Consequently, critical fetches may become very large or even undefined and the definition and interpretation of the critical fetch impractical (Lynch et al., 2016; de Vries et al., 2014a). Moreover, significant spatial variations in sediment supply were found in the Sand Motor region that challenges the spatial aggregation of sediment availability. Alternatively, aeolian sediment transport is expressed in terms of local sediment availability without the need for spatial aggregation (de Vries et al., 2014b; Hoonhout and de Vries, 2016b). Such approach would require detailed measurements on spatiotemporal variations in aeolian sediment availability.

This paper presents detailed measurements of aeolian sediment transport rates from the Sand Motor during a six week field campaign in the fall of 2014. Spatial differences in sediment transport rates reveal the main erosion and deposition areas of aeolian sediment. Temporal variations in aeolian sediment transport are still expected to be correlated with the wind speed, but spatial variations are expected to be correlated with local variations in sediment availability. Understanding local sediment availability ultimately helps improving gross aeolian sediment transport estimates in availability-limited coastal systems.

2. Field site

The Sand Motor mega nourishment was constructed in 2011 along the Delfland coast in The Netherlands (Fig. 1, Stive et al., 2013). The Delfland coast was originally characterized by an alongshore uniform profile with an average dune height of 13 m, a dune foot at about 5 m + MSL and a beach slope of about 1:40.

The Sand Motor is constructed as a 21Mm^3 hook-shaped peninsula that initially protruded about 1 km into the sea and stretched over approximately 2 km alongshore. The original crest height of the Sand Motor was on average about 5 m + MSL and locally 7 m + MSL; both are well above common surge level. Consequently, a significant part of the Sand Motor is uniquely shaped by aeolian processes that redistribute significant amounts of sediments within the Sand Motor region (Hoonhout and de Vries, 2016a).

Sand used for construction of the Sand Motor is medium sand with a median diameter of about 350 µm. The sand is obtained from an offshore borrowing pit in the North Sea and contains many shells and some pebbles, cobbles and other non-erodible material.

The predominant wind direction is south to southwest. Storms have a tendency to be oriented either southwest or northwest. Also the sediment transport potential (Ψ), defined as:

$$\Psi \propto \int u^3 \mathrm{d}t \quad (1)$$

in which u is the wind speed, is predominantly southwesterly or northwesterly oriented. The northwesterly storms are generally accompanied with significant surges as the North Sea is virtually unbounded in northwesterly direction (Fig. 1b).

The contour of the Sand Motor changed significantly in the four years after construction. Tidal forces diffuse about 1 Mm^3 per year along the coast (de Schipper et al., 2016). Four years after construction, the peninsula protrudes about 800 m into the sea and stretches over 4 km alongshore (Fig. 1).

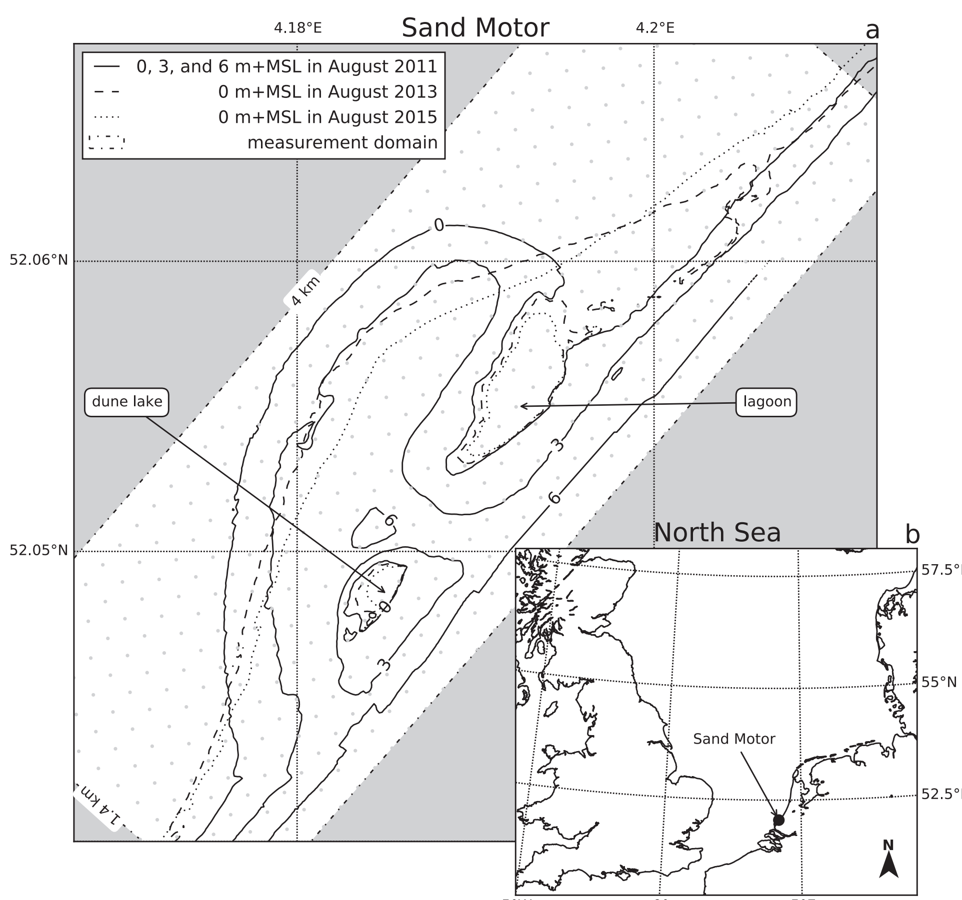

Fig. 1. Location, orientation, appearance and evolution of the Sand Motor between construction 2011 and 2015. The box indicates the measurement domain used in the remainder of this paper. A 100 × 100 m grid aligned with the measurement domain is plotted in gray as reference.