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Aeolian sediment transport on a beach with a varying sediment supply

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ABSTRACT

Variability in aeolian sediment transport rates have traditionally been explain by variability in wind speed. Although it is recognised in literature that limitations in sediment supply can influence sediment transport significantly, most models that predict aeolian sediment transport attribute a dominant role to the magnitude of the wind speed. In this paper it is proposed that spatio-temporal variability of aeolian sediment transport on beaches can be dominated by variations in sediment supply rather than variations in wind speed.

A new dataset containing wind speed, direction and sediment transport is collected during a 3 day field campaign at Vlugtenburg beach, The Netherlands. During the measurement campaign, aeolian sediment transport varied in time with the tide while wind speed remained constant. During low tide, measured transport was significantly larger than during high tide. Measured spatial gradients in sediment transport at the lower and upper beaches during fairly constant wind conditions suggest that aeolian sediment transport on beaches may be partly governed by the spatial variability in sediment supply, with relatively large supply in the intertidal zone when exposed and small supply on the upper beach due to sorting processes. The measurements support earlier findings that the intertidal zone can be significant source of sediment for sediment transport on beaches.

Both a traditional cubic model (with respect to the wind speed) and a newly proposed linear model are fitted to the field data. The fit quality of both types of models are found to be similar.

1. Introduction

This paper aims to interpret aeolian sediment transport on beaches under supply limited conditions using field measurements. These interpretations can be of particular interest when predicting aeolian sediment transport on beaches or in other supply limited environments. Two general prerequisites for aeolian sediment transport are (1) the driving force of the wind and (2) the availability of sediment. The availability of sand or sediment supply is the amount of sediment that can be eroded by wind. Supply limited conditions arise when the wind driven transport capacity can not be reached due to the lack of sediment supply.

Aeolian sediment transport on beaches is often stated to be supply limited (Nickling and Davidson-Arnott, 1990; Houser, 2009). Sediment supply on beaches can be governed by various phenomena such as surface moisture content (Davidson-Arnott et al., 2005), beach slope (Hardisty et al., 1988; de Vries et al., 2012), fetch length (Bauer and Davidson-Arnott, 2002), the presence of vegetation (Arens, 1996) and the presence of lag deposits armoring the sand surface layer (van der Wal, 1998). Some of these supply variables (e.g. moisture content) can vary on short timescales in the order minutes to hours.

The fetch effect is an increase of the aeolian sediment transport rate with distance in the direction of the wind over an erodible surface (see for an overview Delgado-Fernandez (2010) and references therein). The fetch effect is often described as a supply limiting parameter due to a combination of wind direction and beach geometry. In some cases, the beach geometry can vary on short timescales due to tidal influences. The critical fetch distance (F_c) is the fetch distance (F) required for the sediment transport (q) to reach a certain maximum transport (q_m). This maximum transport represents a transport potential and is often determined assuming an equilibrium relation with the wind speed. The maximum transport is in these cases defined to be equal to the wind driven transport capacity. Fig. 1 gives a conceptual representation of the fetch effect after Bauer and Davidson-Arnott (2002).

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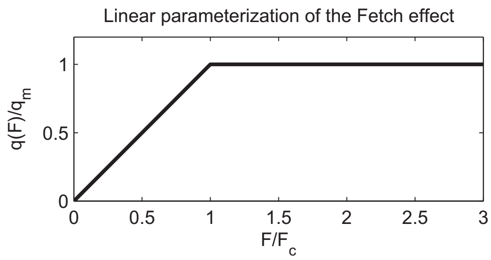

Fig. 1. Conceptual representation of the fetch effect, where transport increases with increasing fetch towards a certain limit. Reference is made to Bauer and Davidson-Arnott (2002) who suggests comparable curves, on a conceptual level, including a smoother transition between the increasing and stable transport.

Various reports are available on the effect of fetch where the estimated critical fetch distances vary from 0 to 200 m (Delgado-Fernandez, 2010; Lynch et al., 2008; Jackson and Cooper, 1999).

Delgado-Fernandez (2011) state that critical fetch lengths could vary due to varying moisture content. This is in line with an earlier finding of Davidson-Arnott et al. (2008) which suggests that moisture content can influence fetch length but the maximum transport rate might also be influenced. At this point a distinction between maximum transport and wind driven transport capacity might be appropriate. Surface moisture content can influence the sediment entrainment and hence the maximum transport. Since the wind driven transport capacity is based on an equilibrium with wind speed, the surface moisture content (which is a supply limiter) does not influence the wind driven transport capacity. To what extent the maximum transport rate is related to wind driven transport capacity in supply limited conditions remains unclear. This complicates the applicability of the fetch model to predict aeolian sediment transport rates at an arbitrary beach.

An alternative interpretation of fetch and aeolian sediment transport in supply limited conditions is provided by de Vries et al. (2014). They argue that, in supply limited conditions, both critical fetch length and maximum transport can be a function of supply rather than wind driven sediment transport capacity. Using this approach for predicting aeolian sediment transport relies heavily on the quantification of sediment supply rather than defining a critical fetch distance and a maximum transport rate. At the same time they consider sediment supply in a holistic way without differentiating between individual supply limiting factors.

Ample evidence of aeolian sediment transport rates at a beach varying due to supply limiting effects can be found in field measurements presented by, among others, Davidson-Arnott et al. (2005), Bauer et al. (2009), Davidson-Arnott and Bauer (2009). On longer timescales the effects of limited sediment supply is reflected by the general over prediction of sediment transport by sediment transport formulations that do not account for supply limited conditions. (see for instance Sarre, 1988; Sherman et al., 1998; Kroon and Hoekstra, 1990; Sherman et al., 2013)

In conditions where sediment supply is abundant (e.g. desert situations), rates of aeolian sediment transport can be estimated using the well established theory by Bagnold (1954). The theory by Bagnold (1954) relates a higher (often cubic) power of the wind speed to equilibrium sediment transport rates. For situations where supply is limited, such limitations are often accounted for in a pragmatic way by adding empirical parameters to Bagnold (1954) type formulations when fitting field data (e.g. Kroon and Hoekstra, 1990; Arens, 1996; Delgado-Fernandez, 2011). Generic models for these empirical parameters are unavailable and consequently the use of such formulations is highly site specific. Therefore, at present, the generic quantitative prediction capability of aeolian sediment transport rates on beaches is very limited (Sherman and Li, 2012; Bauer et al., 1996).

de Vries et al. (2014) consider sediment supply to be independent of wind conditions. In their model they propose to set a discrete limit to sediment supply as an alternative to correcting Bagnold (1954) type sediment transport formulations for supply limiting effects. In this approach, maximum transport and transport potential are unrelated in supply limited situations and can therefore be of different magnitude (where maximum transport is always smaller or equal to the transport capacity). While wind driven sediment transport capacity (q_m) used in fetch theories is not per se a function of supply, the application of the critical fetch approach seems ambiguous when predicting sediment transport under supply limited situations.

Furthermore, de Vries et al. (2014) suggest that aeolian sediment transport on beaches could be linearly related to wind speed. This linear relation is based on the principle that sediment transport is a product of wind velocity and an average sediment concentration (in the air). It is argued that this average sediment concentration could be determined to a great extent by the available supply rather than the wind speed. At this stage the formulated linear model does not have predictive skill however, de Vries et al. (2014) have shown that for a synthetic case the linear fit could possibly be used to derive information on the magnitude of the sediment supply. The linear model could therefore provide a tool to assess the variability in supply magnitude during field experiments where sediment transport rates and wind velocities are measured.

This study was driven by the desire to be able to interpret and predict aeolian sediment transport on beaches. A dedicated field experiment along the Dutch coast is undertaken with the specific aim of gaining insights into spatio-temporal variability of sediment supply on beaches. It is hypothesized that sediment supply governs aeolian sediment transport rates on the beach and that the linear model proposed by de Vries et al. (2014) can be used to describe supply limited aeolian sediment transport.

2. Field site and experimental design

Field measurements were conducted from 6 to 10 December 2010 at Vlugtenburg beach located on the south west of the Holland coast (see Fig. 2). At the time of the measurements, beach slopes were are roughly between 1:40 and 1:50 and the mean grain size (D_{50}) was in the order of 200–300 μm. The beach can generally be categorized as a dissipative beach according to the geographical framework presented by Short and Hesp (1982).

The beach shape is partly the result of a major nourishment which was implemented (in 2008) two years before the measurements (de Schipper et al., 2012). The nourishment has resulted in an artificial beach, dune and foreshore. After the nourishment the coastal profile has been shaped by marine and aeolian forces. The nourished sand contains a relatively large amount of shell fragments. Due to sorting processes over time, the shell fragments form lag deposits at the upper beach. In the intertidal zone, the lag deposits are reworked. van der Wal (1998) reports on similar spatial distributions of lag deposits (consisting of shell fragments) at different nourishment sites along the Dutch coast. Figs. 3 and 4 illustrate the local morphology and surface characteristics at the measurement site.

Generally, mean wave heights and periods along the Dutch coast are 1.2 m and 5 s respectively and alongshore differences in wave climate are small (Wijnberg and Terwindt, 1995). The tide is semi diurnal with a neap-, spring-tidal range of respectively 1.2–2.2 m. The horizontal cross shore excursion of the waterline due to the tide is around 80–100 m. As a result, the tide creates a significant temporal variability of beach width and therefore wind fetch during onshore and oblique onshore winds. Measurements of