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Field testing, comparison, and discussion of five aeolian sand transport measuring devices operating on different measuring principles

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A R T I C L E I N F O

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A B S T R A C T

Five types of sediment samplers designed to measure aeolian sand transport were tested during a wind erosion event on the Sand Motor, an area on the west coast of the Netherlands prone to severe wind erosion. Each of the samplers operates on a different principle. The MWAC (Modified Wilson And Cooke) is a passive segmented trap. The modified Leatherman sampler is a passive vertically integrating trap. The Saltiphone is an acoustic sampler that registers grain impacts on a microphone. The Wenglor sampler is an optical sensor that detects particles as they pass through a laser beam. The SANTRI (Standalone AeoliaN Transport Real-time Instrument) detects particles travelling through an infrared beam, but in different channels each associated with a particular grain size spectrum. A procedure is presented to transform the data output, which is different for each sampler, to a common standard so that the samplers can be objectively compared and their relative efficiency calculated. Results show that the efficiency of the samplers is comparable despite the differences in operating principle and the instrumental and environmental uncertainties associated to working with particle samplers in field conditions. The ability of the samplers to register the temporal evolution of a wind erosion event is investigated. The strengths and weaknesses of the samplers are discussed. Some problems inherent to optical sensors are looked at in more detail. Finally, suggestions are made for further improvement of the samplers.

1. Introduction

Since the introduction of the classic Bagnold trap (Bagnold, 1938), numerous devices have been developed to measure aeolian sand transport. They vary from very simple, passive traps to highly sophisticated electronic sensors. To measure the horizontal sand flux, passive vertically integrating samplers (Bagnold, 1938; Leatherman 1978, Davidson-Arnott and Bauer, 2009), passive segmented traps (WITSEG: Dong et al., 2004; MWAC: Wilson and Cooke, 1980; Kuntze et al., 1990; BSNE: Fryrear, 1986; BEST: Basaran et al., 2011), mesh-style traps for short-term deployments (Sherman et al., 2014), swinging traps (Hilton et al., 2017), and many other concepts have been applied. When the focus is on measuring sediment transport in real-time, one can use continuously-weighing sand traps (Lee, 1987; Janssen and Tetzlaff, 1991; Jackson, 1996; Bauer and Namikas, 1998) or electronic sensors with a high time resolution. The latter category of samplers has become very popular since the introduction of the Sensit (Gillette and Stockton, 1989; Stockton and Gillette, 1990), which uses a piezoelectric crystal that registers sand impacts. The Safire (Baas, 2004; Gillies et al., 2006, 2013; Lancaster et al., 2010) is a similar device that intends to be more economical. The Saltiphone (Spaan and van den Abeele, 1991) is an impact sensor that registers grain impacts on the membrane of a microphone. The Miniphone, introduced by Ellis et al. (2009), is a modified electret microphone that detects the impacts of individual grains.

Recently, several optical electronic devices have been developed that have proved to be very useful under field conditions. Mikami et al. (2005) experimented with, and continue to develop the sand particle counter (SPC). This instrument relies on laser light scattering to infer a particle size distribution for particles with diameters from 30 to 667 µm. Another optical device (Wenglor) has been tested by

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Hugenholtz and Barchyn (2011), Barchyn et al. (2014) and Duarte-Campos et al. (2017). Etyemezian et al. (2017) report on an optical gate sensor integrated into a setup called SANTRI (Standalone AeoliaN Transport Real-time Instrument). They argue that because the signal response of the sensor is proportional to the cross-sectional area of the grains travelling through the optical gate, it should be possible to estimate the particle size distribution.

Numerous papers have been published of studies testing and comparing sand transport measuring devices (Leatherman, 1978; Jones and Willetts, 1979; Arens and van der Lee, 1995; Nickling and McKenna Neuman, 1997; Goossens et al., 2000; Namikas, 2002; Li and Ni, 2003; Zobeck et al., 2003; Dong et al., 2004; Cabrera and Alonso, 2010; Tidjani et al., 2011; Poortinga et al., 2013, to mention only a few contributions). Perhaps the most fundamental methodological question that then arises is: Can we compare data that were obtained with samplers that operate on sometimes entirely different measuring principles? If so, how should the data be processed in each case to allow for objective comparison between samplers?

In this study we test a set of sand transport samplers that operate on diverse measuring principles and compare the results after the data have been processed towards a same standard so that they can be objectively compared. The test was performed on the Sand Motor, a nourishment of sand on the west coast of the Netherlands, an area that is prone to frequent wind erosion. The samplers included a passive, vertically integrating continuously-weighing trap, a passive segmented trap, an acoustic impact sensor, an optical electronic sensor, and a recently developed optical gate sensor with multiple channels each of which is sensitive to a particular grain size class. We present the methodology to objectively compare the data, discuss the strengths, weaknesses and applicability of each sampler, and provide suggestions for further improvement of the instruments.

2. Study area

The study was conducted on the Sand Motor (also called Sand Engine, Dutch: Zandmotor), a unique, approximately 1 km^2 large nourishment of sand with an initial volume of 21.5 million m^3 that was laid down for coastal protection on the west coast of the Netherlands near The Hague (Fig. 1). Its design stems from the philosophy of 'Building with Nature' (De Vriend and Van Koningsveld, 2012), a coastal management strategy that aims to provide coastal safety by utilizing natural processes. Through wave and wind action, the Sand Motor gradually releases its sand along the coastline, thereby reinforcing the beach and dunes against storm surges and sea level rise (Nolet et al., 2014; De Schipper et al., 2016). A net negative sediment balance is thus counteracted, while the coastal ecosystem is preserved (Stive et al., 2013).

The Sand Motor is located along a stretch of the Delfland coast and has a hook-shaped design (Fig. 1) that mirrors the natural onshore migration of an intertidal sandbar. The tide near The Hague is semi-diurnal with a spring-neap tidal amplitude around 1.5–2.0 m, generating alongshore currents with velocities up to 0.5 $m\,s^{-1}$ (Luijendijk et al., 2017). Just after its construction in summer 2011 the Sand Motor had a surface area of about 128 ha, extending 2.5 km along the coastline and protruding 1 km into the sea. Natural processes have since then redistributed the sand at high rates (De Schipper et al., 2016). Fig. 1 provides a snapshot of the morphology of the Sand Motor during autumn 2015.

Climate in the Netherlands is temperate humid, with strong seasonal contrasts. The dominant wind direction is southwest, but during the wind erosion event analyzed in this study the wind blew offshore, coming from the east.

Annual average rainfall near The Hague is around 880 mm. During the wind erosion event analyzed here, no rain occurred.

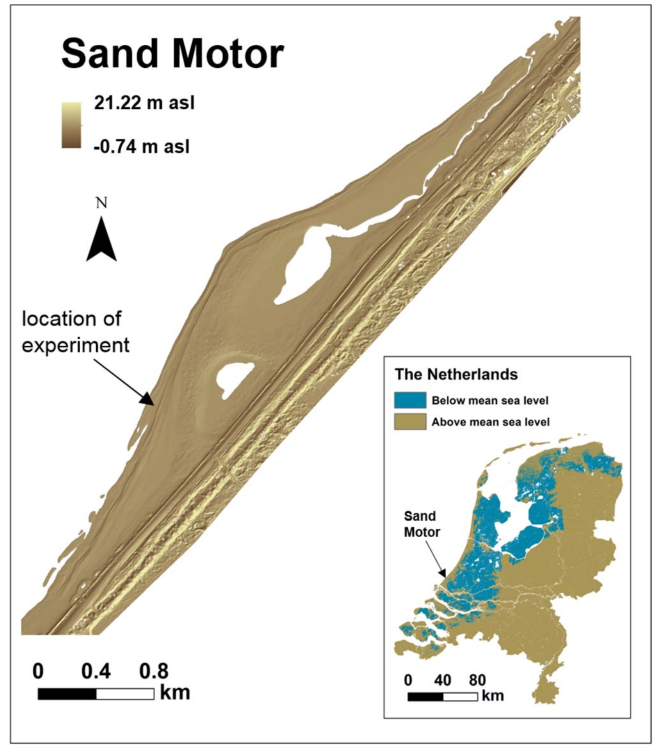

Fig. 1. Location of the experimental site on the Sand Motor along the Dutch coast. The inset map of the Netherlands illustrates the importance of coastal defense as large parts of the country are below mean sea level. The map of the Sand Motor was derived from airborne lidar during a flight in October 2015.

3. Description of samplers

3.1. MWAC sampler

The MWAC sampler is based on an original concept developed by Wilson and Cooke (1980). The sampler consists of a plastic bottle to which an inlet tube and an outlet tube have been added (Fig. 2). The bottle serves as the settling chamber for the wind-transported grains. In the original version the bottle was installed vertically, with the inlet oriented to the wind. Sand entering the bottle deposits due to the pressure drop created by the difference in diameter between the bottle and the inlet and outlet tubes. The clean air then discharges from the bottle via the outlet. The initial concept was later slightly modified by Kuntze et al. (1990), who attached the bottle in a horizontal position to a vertical mast. A wind vane ensures that the inlet faces the wind. Attaching several bottles at different levels to the mast can measure vertical flux profiles (Sterk, 1993). In this study, the MWAC was tested with the bottles oriented in the horizontal position. Sediment was collected at 7 heights above the ground, at approximately 8, 15, 22, 30, 50, 75, and 100 cm.

3.2. Saltiphone

The Saltiphone is an acoustic sensor that records the impacts of saltating particles on a sensitive microphone submerged in the saltation layer. Preliminary versions of the sensor have been tested by van der Linden (1985). The final version, which is shown in Fig. 3a, was described by Spaan and van den Abeele (1991). A technical scheme is given in Fig. 3b. The instrument consists of a microphone containing a sensitive membrane 10 mm in diameter, which is installed in the middle of a stainless-steel tube 130 mm long and 50 mm in diameter. The tube protects the microphone against severe weather conditions. To keep the microphone's membrane perpendicular to the wind at all times, two vanes are attached to the back of the tube. The tube itself is mounted on