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Detection of aeolian transport in coastal images

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ABSTRACT

Optical remote sensing provides a low cost method of documenting surface conditions over extended periods of time. Its utility in resolving large scale aeolian transport events is examined in this paper. To this end, over 1800 images taken over a three month period by a stationary camera in a coastal setting are classified as containing/not containing aeolian transport using both a manual and automated approach. In both cases transport is inferred by the identification of aeolian streamers within a given image. With regards to the manual approach, images were visually examined by three users. There was good agreement between the different users with 77.8% of transport identifications being unanimous. Comparison of the user results with measured transport highlights that observations of transport in images coincide with increased particle counts. The particle counts indicate that transport is dominated by a series of discernible transport events. Transport is observed in images throughout the duration of these events. Manually processing the images is a laborious process. A method is presented which allows for the automated detection of images containing transport. The method utilises 2D-DFTs to exploit the linear appearance of streamers in images. Relative to the manual classifications which serve as ground truth, the method performs well in identifying images containing transport with values of precision, recall and F1 score $\geqslant 0.85$.

1. Introduction

Dunes play an important role in protecting low lying coastal areas against coastal flooding. Their growth and recovery after storm erosion requires the supply of sediment from the subaerial beach by wind-driven processes. Whilst recent approaches in coastal management try to utilise these processes to promote dune growth (Stive et al., 2013), our ability to predict the sediment supply over relevant timescales (*i.e.* monthly to annual) remains poor.

Across these timescales, sediment supply is typically calculated by applying variants of the traditional, semi-empirical process-based transport equations (*e.g.* Bagnold, 1941; Kawamura, 1951) to routine meteorological data (*e.g.* Hsu, 1974). At process-scale, these equations, which assume steady-state transport, over predict transport rates in coastal settings (Sherman and Li, 2012). In part, this is due to their failure to (appropriately) account for a range of conditions which characterise coastal environments, *e.g.* moisture (*e.g.* Wiggs et al., 2004; Davidson-Arnott and Bauer, 2009) and lag deposits (*e.g.* van der Wal, 1998; Hoonhout and de Vries, 2017b). In conjunction with the spatial constraints placed by beach width (*e.g.* Delgado-Fernandez, 2010), these factors inhibit the evolution of the transport system to fully steady state conditions (Davidson-Arnott and Bauer, 2009). Unsurprisingly, when these transport equations are applied over longer time scales they overestimate sediment supply (*e.g.* Keijsers et al., 2014). Consequently, the calculated sediment supply is often regarded as an upper bound and is termed potential transport. When considered over monthly time-scales, the potential transport can exhibit conflicting trends with the observed supply (*e.g.* Davidson-Arnott and Law, 1996). In part, this a consequence of a significant proportion of the calculated potential transport being contributed by a limited number of significant winds events, not all of which contribute to the actual observed sediment supply. Though a few major transport events are likely to be responsible for the majority of sediment supply to the dunes, the strongest winds events do not always result in the significant transport due to the co-occurrence of conditions such as precipitation events, storm surges *etc.*, which shut the transport system down (Delgado-Fernandez and Davidson-Arnott, 2010; Delgado-Fernandez, 2011). The interaction of the various supply limiting conditions make it difficult to predict when a wind event will result in a significant transport event.

A lack of understanding as to when the transport system is shut down hinders our ability to predict longer term sediment supply. Consequently, long-term datasets that are able to document the occurrence of large scale transport events are desirable. The linkage of such datasets to surface, tidal, and atmospheric conditions, can provide

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insight into conditions that are (un-) favourable for wind-driven transport. The creation of datasets with sufficient spatial and temporal coverage using traditional in situ techniques is challenging. In this regard, coastal imagery, which documents surface conditions over a wide area during daylight hours for however long the camera system is operational, has a number of advantages (*e.g.* Holman and Stanley, 2007). The quantitative use of images requires that relevant physical processes leave an optical signal that can be exploited. Whilst progress has been made in using images to quantify factors that may influence the occurrence of transport events, *e.g.* surface moisture (Darke et al., 2009; Delgado-Fernandez et al., 2009) and shoreline position, (*e.g.* Aarninkhof et al., 2003; Hoonhout et al., 2015) and hence fetch length, their application in identifying transport events remains limited.

One of the ubiquitous features of large scale transport events in coastal environments is the presence of regions of intense saltation activity and high sediment concentrations, known as streamers. With widths in the order of 0.2 m, length scales in excess of 50 m, and horizontal separations of 1 m, streamers snake across the surface propagating in the downwind direction (Baas and Sherman, 2005), contributing significantly to the total transport rates (Ellis et al., 2012). As highlighted in Fig. 1a, streamers are frequently observed within coastal images, particularly in areas where the underlying sediment is relatively moist. This provides relatively strong contrast differences with the dry and thus lighter sediment of the streamers. The identification of streamers in instantaneous snap-shot images can therefore confirm the occurrence of wind-driven transport at a given moment in time. In contrast, the rapid movement of streamers means they are averaged out of time averaged images. This is illustrated in Fig. 1b. The application of images in the study of streamers remains limited. Exploratory work, indicates that they may have utility in resolving the spatial and temporal structure of streamers (Sherman et al., 2013). The manual identification of streamers in images has been used to document the occurrence of transport events (van and Wijnberg, 2016). Manual identification is a slow process, and it remains unclear how user bias influences the identification of streamers.

The aim of this paper is to examine the utility of routine coastal imagery in resolving large scale wind-driven transport events. To this end, a number of users manually classified >1800 coastal images as containing/ not containing wind-driven transport. The subjectivity involved in manual classification is examined and the classified images are related to measured transport. A method is presented which seeks to classify images containing transport in an automated manner.

The remainder of this paper is organised as follows: The field site and available data are introduced in Section 2. Section 3 details the steps adopted to classify images manually and in an automated manner. The results of both approaches are given in Section 4 and discussed in Section 5. Finally, conclusions are drawn in Section 6.

2. Field site & data

Coastal images from the Sand Motor are considered in this study. The site is an artificial peninsula located on the west coast of the Netherlands. Upon its completion in 2011, it consisted of 21 Mm^3 of mined offshore sediment distributed over alongshore and cross-shore distances of 2.4 km and 1 km respectively (Stive et al., 2013). The project aims to utilise natural processes to redistribute this sediment, providing coastal protection along the adjacent coastline over decadal timescales. The supply of sediment to dunes by wind-driven processes is important to this. The topography of the site in October 2014 is shown in Fig. 2.

A camera station is located at the centre of the site and has been collecting images since 2013. The station is part of the larger network of Argus stations which collect coastal image data in standardised way (Holman and Stanley, 2007). Argus stations are primarily designed for use in nearshore studies and are typically mounted ≈40 m above the beach surface to provide optimal coverage for these purposes. The east facing camera overlooking the lagoon area is considered in this study (see Fig. 2). The lagoon area is infilling as a consequence of wind-driven transport (Hoonhout and de Vries, 2017a). When fully operational, the camera collects timestamped RGB snapshot (snap) and time exposure (timex) images concurrently every 30 min during daylight hours. The latter image type represents the mathematical mean of all images taken over a 10 min window.

A Campbell Scientific meteorological station is mounted on top of the camera tower (height ≈44 m), providing measurements of minutely averaged wind speeds and directions. Tidal levels are measured at a tide gauge located 10 km NW of the site every 10 min. The site is subject to LiDAR surveys every 6 months, providing regular topographic measurements of the subaerial beach and dunes at 2 × 2 m resolution. In situ aeolian transport measurements are available between September 17 and October 23, 2014. During this period Hoonhout and de Vries (2017b) deployed a series of masts equipped with Wenglor forks, providing particle count measurements at heights of 0.03 m, 0.1 m and 0.25 m above the surface, measured at a frequency of 1 Hz. The spatial arrangement of masts varied through time. The mast closest to the field of view for each arrangement is shown in Fig. 2.

Given the available transport data, images taken during daylight hours in August, September and October 2014 are considered in this

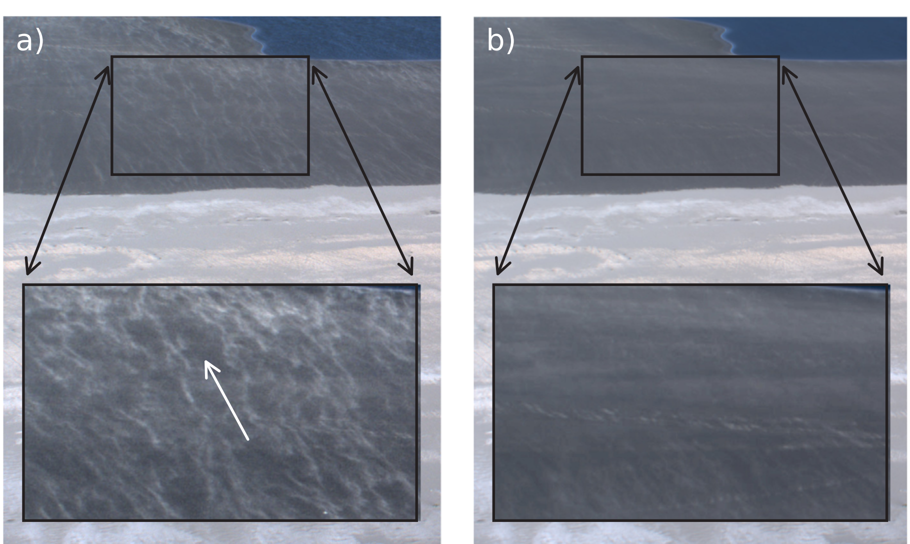

Fig. 1. (a) Streamers in a snap shot image at the Sand Motor. They are most noticeable in the upper half of the image (intertidal area) where there is a good contrast with underlying moist sediment. This area is enlarged in lower half of the image. Streamers are of a lighter colour than the underlying beach. The white arrow highlights their propagation direction. (b) Concurrent time exposure image (average of all images taken within 10 min window) in which the streamers are averaged out.

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