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THE INFLUENCE OF SPATIALLY VARYING SUPPLY ON COASTAL AEOLIAN TRANSPORT: A FIELD EXPERIMENT

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Abstract: Supply-limiting factors, like moisture content and sediment armoring, influence coastal aeolian sediment transport and subsequently dune evolution significantly. We organized a 6-week field experiment on the influence of spatiotemporal variations in supply on coastal aeolian sediment transport at the Sand Motor, The Netherlands. Due to the presence of a strongly curved coastline and complex intertidal bathymetries, a large spatial variation in supply is to be expected at the Sand Motor, which makes the area particularly suitable for a field experiment on this subject. Preliminary results show that not the largest surface area of sand, nor the biggest fetch or the most severe storm result in significant aeolian sediment transport events, but persistent moderate winds over large intertidal beaches are the key to coastal aeolian transport and subsequently dune evolution.

Introduction

Aeolian sediment transport rates and volumes in coastal environments are generally overestimated making long term aeolian flux estimates highly unreliable (e.g. Davidson-Arnott et al., 2009; Jackson and Cooper, 1999; Lynch et al., 2008). A major limitation of these instantaneous flux estimations is that they are highly empirical and do not adequately account for the influence of supply-limiting factors, like sediment armoring and moisture content (e.g. Wiggs et al., 2004; Davidson-Arnott et al., 2008; Bauer et al., 2009; De Vries et al., 2014). Observations of the sub-aerial morphology and coastal aeolian transport events along many beaches suggest that the dry beach area is morphologically relatively static on a daily to seasonal time scale (De Vries et al., these proceedings). It has been suggested that the intertidal zone is a primary source of sediment for backshore aggradation and dune evolution (e.g. Houser, 2009), which is supported by observations demonstrating a strong correlation between aeolian transport and the tide level (e.g. Arens, 1996; de Vries et al., 2011). This suggests that in coastal environments the spatiotemporal differences in supply play an important role in estimating aeolian transport rates and volumes, perhaps even more so than traditional metrics as fetch and beach width.

Starting September 15, 2014, we organized the 6-week MegaPeX field experiment at the Sand Motor, The Netherlands (Figure 1). Extensive measurements on aeolian transport and environmental factors regulating backshore transport were performed as part of MegaPeX. The data are used to study the influence of spatially varying supply on coastal aeolian sediment transport.

Figure 1: Location of the Sand Motor.

Hypotheses and objectives

The objective of the field experiment is to validate assumed relations between the spatiotemporal gradients in wind-driven sediment fluxes, sediment size distribution of the top layer of the beach, moisture content, topography and wind velocity and direction. We have formulated two main hypotheses:

1. The intertidal beach is the most important source of sediment for coastal aeolian transport and subsequently dune growth;
2. Significant spatiotemporal gradients in aeolian sediment flux are related to sediment size distribution, moisture content and topography.

Past field observations show that annual morphological change is concentrated in the intertidal and dune regions, but often limited in the dry beach area (De Vries et al., these proceedings). These dry and morphologically static areas may correspond to armored beaches where a coarse layer of sediment prevents further erosion. This also holds for a huge exposed bare area, like the Sand Motor that is nowadays largely covered with shells and coarse sediments (Figure 2). These observations suggest that also at the Sand Motor the intertidal beach has been the main supplier of sediment for coastal aeolian processes and subsequently dune growth.

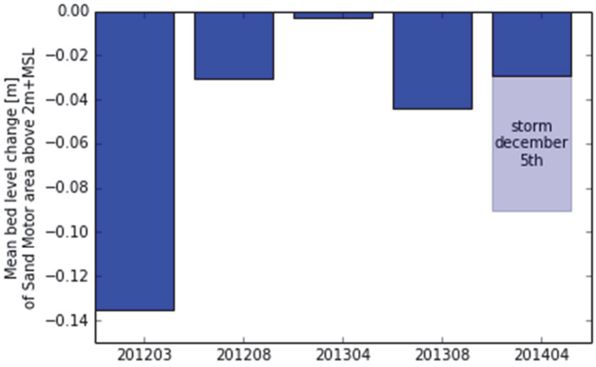

Figure 2: Mean bed level change in Sand Motor area above regular high water mark due. Erosion quickly diminished after construction in 2011. A single storm event on December 5, 2013 resulted in significant erosion due to marine rather than aeolian processes.

Field site

The field site is a located along a 20 km stretch of sandy coast in The Netherlands. This area is monitored using remote sensing techniques and bimonthly topographic and bathymetric surveys for the past two years and will continue to be monitored for at least another three years. The field site includes a 20 Mm^3 hook-shaped nourishment, called the Sand Motor (or Engine; Figure 1; Stive et al., 2013). The Sand Motor covers an area of about one kilometer cross-shore and four kilometers alongshore. A significant part (70%) of the Sand Motor is located above the high water mark, up to 6 m above mean sea level, and is hence susceptible for aeolian processes. The tidal range around the Sand Motor is about 1.5 m, while the dominant wind direction is southwest although high-energy events are often from the northwest.

Aeolian measurements during MegaPeX are concentrated on the southern flank of the Sand Motor that is, apart from the dune lake, relatively uniform. In this area the Sand Motor welds to the original coast accommodating an extensive intertidal beach with an active swash bar system that generates large spatiotemporal gradients in supply. Together with the favorable orientation to the governing southwesterly winds, this area is particularly suitable for the research questions motivating this study.

Equipment and deployments

Due to the large spatial variation in supply that is expected at the Sand Motor, a flexible measurement set-up is used, such that the spatial configuration of a measurement transect can change depending on the wind direction. The measurement set-up consists of 8 masts with battery power and data loggers. These masts can be deployed in a single large transect or multiple smaller transects.

Figure 3: Measurement setup of masts with the wind speed and direction sensor and laser sensors

Each mast can be equipped with a Gill 2D WindSonic ultrasonic wind speed and direction sensor at a height of 1.8m above the bed, a Trime PICO32 soil moisture sensor buried in the soil horizontally and multiple Wenglor laser sensors for saltation measurements at variable heights (Figure 3). The Wenglor laser sensors register passing particles of 50 μm and larger with a frequency of 10 kHz using a laser beam of 0.6 mm. The particle counts are accumulated by one of the HOBO pulse counters. A HOBO Energy data logger logs all sensors, including the pulse counters, at 1 Hz. The masts can be rotated, but are not self-rotating to the wind as the intention is to relocate masts depending on the wind.

A single measurement transect consists at least of four masts: two in the intertidal area in order to capture the supply rate from the assumed source region, one just above the high water mark to capture the sediment influx from the intertidal area on to the dry upper beach and one higher up the beach to capture any additional supply from the dry beach itself. Two of these transects can be deployed simultaneously.

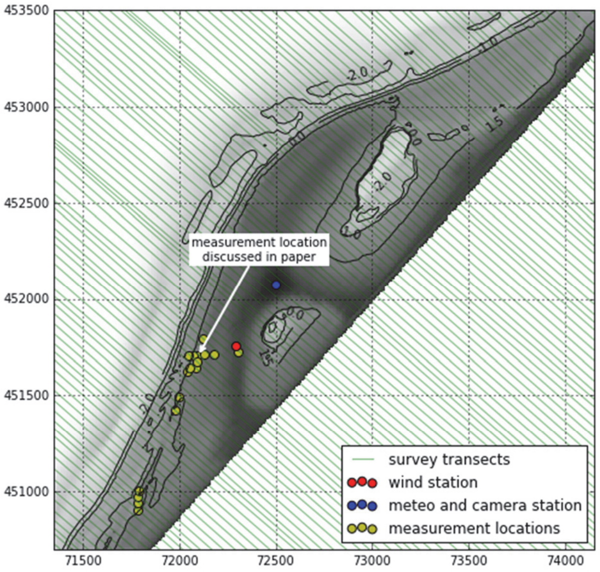

Figure 4: Overview of measurement locations

During MegaPeX a macro camera was used to photograph the top layer of the beach from which grain size distributions can be estimated. Leatherman sediment traps were installed alongside two of the masts as well as at strategic locations along the dune foot. A separate wind station with three cup anemometers at heights 0.5, 1.0 and 1.8 m was present at a stationary location at the high beach for the entire duration of the experiment. A meteorological station was present at the heart of the Sand Motor providing measurements on precipitation, humidity, solar radiation and wind speed and direction. An overview of the measurement locations is given in Figure 4.

Before and after the experiment a full topographic and bathymetric survey was performed as well as halfway the experiment. Daily measurements of the intertidal and swash morphology along 21 transects were performed as well, while the dry beach and dunes were monitored weekly along these transects.

Environmental conditions

During the field experiment winds were mainly from the south or southwest with several high energy events from north or northwesterly directions as shown in Figure 5. It can be seen from this figure that 8% of the time the wind blew from the south with a speed exceeding 4 m/s. About 20% of the time wind speeds were below 4 m/s, which is below the critical threshold velocity such that no aeolian transport typically occurs. Assuming a standard $q \sim u^3$ relationship between the transport rate q and the wind velocity u the time integrated value of u^3 provides a measure for the total potential transport for each wind direction as shown in Figure 5. The cubic term results in the large transport potential from individual storm events even if those events are infrequent or improbable. That explains how one high energy event from northwesterly direction in particular is revealed by the potential transport. This significant storm surge hit the Sand Motor at the end of the experiment on October 22, 2014 from the northwest with water levels rising up to 3 m+MSL, which is about 2 m above the regular high water. During the field experiment the rainfall accumulated to about 80 mm, mainly concentrated in the second half of the experiment and especially the week of October, 6 2014 and a few distinct events later on.

Results

The field experiment resulted in an extensive dataset on coastal aeolian transport with consistent and reliable data running from September 17, 2014 until October 23, 2014. In this paper we focus on a single measurement location that was occupied by one of the measurement masts for almost the entire experiment (Figure 4). This particular location is especially of interest for research on the influence of supply on aeolian transport rates since its sediment source areas are distinct. The mast was located just landward of the high water mark and therefore southwesterly to northerly winds transported sediment directly from the intertidal beach (with varying width). Conversely, winds blowing from other directions transported sediment from the dry upper beach without clear intertidal origin.

Figure 5 shows the distribution of the wind directions for different threshold wind velocities together with the normalized particle counts at the measurement location. The normalized particle counts are obtained by adding the time series for the particle counts of the different Wenglor laser sensors into a single time series and binning the result into discrete directional bins of 10°. The result is normalized to sum to one (and scaled to fit the plot). Any log records that are obtained while the orientation of the laser sensor was more than 60° off with respect to the instantaneous wind direction were discarded from the analysis to minimize the underestimation of instantaneous transport rates due to sheltering effects of the instrument itself. Note that this led to the removal of 20% of the data.

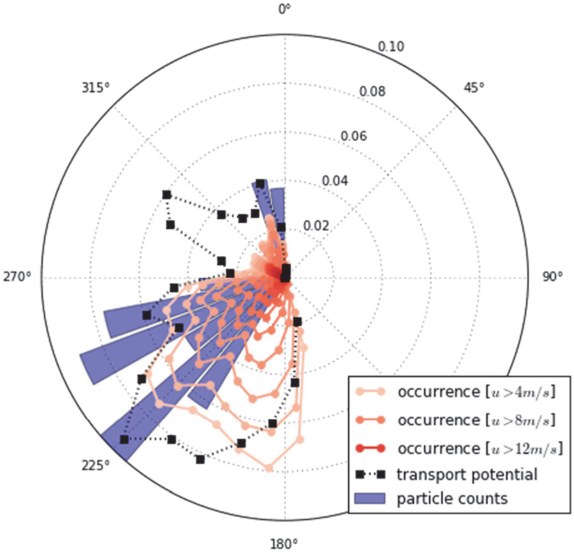

Figure 5: Occurrence of wind direction and speed during the MegaPeX field experiment, total potential transport and the fraction of total particle counts from per wind.

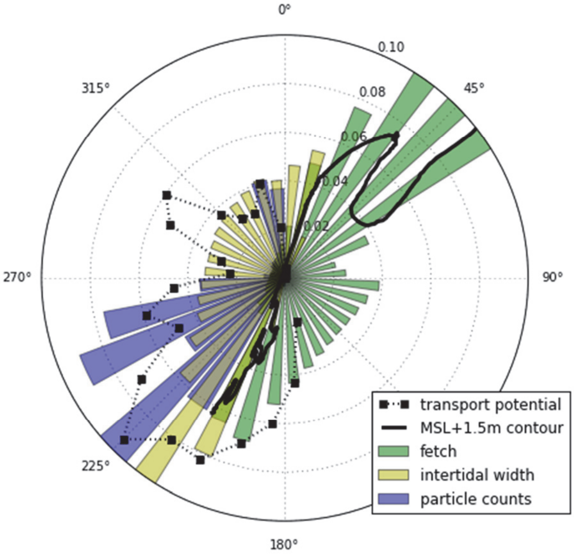

Figure 6: Total potential transport, particle counts and a visualization of the available fetch distances and intertidal beach widths as seen from the measurement location.

The particle counts in Figure 5 show two distinct peaks: one to the north (340° - 360°) and one to the westsouthwest (210° – 270°). Both peaks correspond reasonably well with the observed wind distribution and especially with the potential transport that were discussed earlier. Traditional aeolian sediment transport laws ($q \sim u^3$) seem to qualitatively fit to the data; however, considerable differences can be distinguished as well. First, the wind data suggests that largest transport should be from the southwest (160° – 270°), but this is not represented in the particle counts. Second, the distinct peak in potential transport in northwesterly direction (290° - 310°) does not coincide with any measured transport of the same order of magnitude.

According to our hypothesis (1) the differences could be explained in the aforementioned supply limitations. Figure 6 shows the same plots for the potential transport and measured particle counts against a visualization of the available fetch distance and effective intertidal beach width (not to scale) depending on the wind direction as seen from the measurement location. The fetch is determined based on the shortest distance from the measurement location to either the -1 m+MSL or 10 m+MSL contour in each wind direction. The intertidal beach width is defined as the longest uninterrupted distance in the area enclosed by the 1.5 m+MSL and -1 m+MSL bed contour along each wind direction. In addition, the 1.5 m+MSL bed contour of the Sand Motor is added to the graph that approximately indicates the high water mark.

Seen from the measurement location, fetch and intertidal beach width are shortest to the west. Turning to the north, the width of the intertidal beach does not change significantly, but the fetch, and thus the effective intertidal beach width does due to an oblique crossing of the intertidal area. Turning to the south, the intertidal beach width is highly variable. As a result, the large intertidal widths result in a large potential fetch length under southwesterly winds from the perspective of the fixed measurement location. Despite the large fetch lengths from the northeast, winds from that direction are rare in the Netherlands and there were no instances of wind from that direction recorded during the experiment. On the other hand, the majority of the more common southeasterly to southwesterly wind directions also has considerable fetches, but only from the very southwesterly directions sediment transport was measured to the order of magnitude that could be expected from these winds. The important difference between the directions that received both wind and sediment and the directions that received just wind is that the former had limited fetches, but entirely over the intertidal beach, and the latter had significant fetches, but entirely over the dry beach.

The distinct peak in potential transport in northwesterly direction also shows a discrepancy with the measured transport rates. This peak represents the first 8 hours of a storm surge that occurred in the night of October 21 to 22 and came with a considerable surge of almost 3 m+MSL, effectively flooding the entire intertidal beach for over 24 hours (Figure 7). During these first 8 hours no significant precipitation was observed that hampered aeolian sediment transport measurements, yet no transport was measured in the order of magnitude of the potential transport. This discrepancy can potentially be accredited to the flooding of the intertidal area.

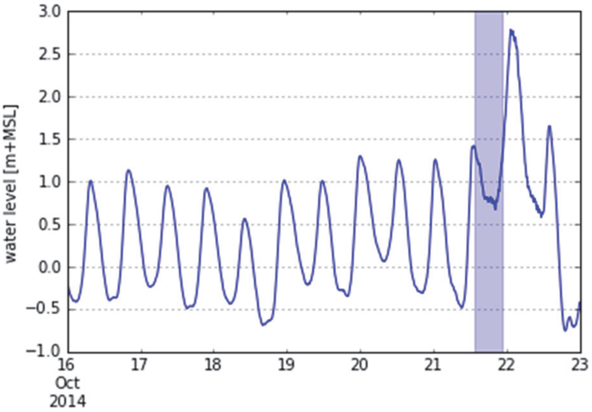

Figure 7: Offshore water level in last week of the field experiment. The shaded area indicates the period of severe northwesterly winds that caused the peak in potential transport.

Conclusions

The complex morphology of the Sand Motor appeared to be a suitable setting for research on the influence of supply on coastal aeolian transport. The MegaPeX field experiment provided an extensive dataset on coastal aeolian transport and how the magnitude of transport is regulated by supply. Preliminary assessment of these data shows strong relations between particle counts and source area and support the hypothesis of the intertidal area being the primary source region of aeolian sediment. Preliminary conclusions from this assessment are:

- Measured transport rates were largest from wind directions where intertidal beaches are a potential source of sediment;

- Measured transport rates were smallest from wind directions where only dry beach or dune areas were a potential source of sediment;

- Measured transport rates during storms that caused a surge that flooded the intertidal region over a long period were significantly lower compared to situations with more moderate winds;
- No significant correlation was found between measured transport rates and available fetch.

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