In: Proceedings of Coastal Sediments 2015, San Diego.
Wang. P, Rosati, J.D., and Cheng, J. (Eds.), 2015, World Scientific. 12 pages.

AEOLIAN ACTIVITY ON A PENINSULA-SHAPED MEGA NOURISHMENT

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Abstract: The peninsula-shaped Sand Motor mega nourishment is a pilot project that, amongst others, serves the purpose of testing and learning about 'Building with Nature' concepts. Therefore, a range of monitoring and data collection initiatives is accompanying this project, including an Argus video monitoring system. Our study focusses on assessing and understanding the contribution of the aeolian component to the development of the mega-nourishment and the neighboring foredunes. Preliminary results indicate a decrease in annual aeolian transport rates over the period 2011/2012 to 2013/2014.

Introduction

Designing solutions for coastal problems that use natural processes in a constructive way, requires a sufficient level of understanding of those processes. Due to the complexity of interactions between processes it may often not be clear to what extent our knowledge is 'sufficient'. Therefore pilot projects will be required to eventually test the concepts and improve on them. In the Netherlands the 'Sand Motor' mega nourishment is such a pilot project. The Sand Motor (also referred to as 'Sand Engine'), constructed in 2011, is a peninsula-shaped nourishment with a volume of 21.5 Mm^3 on the west coast of the Netherlands (Figure 1).

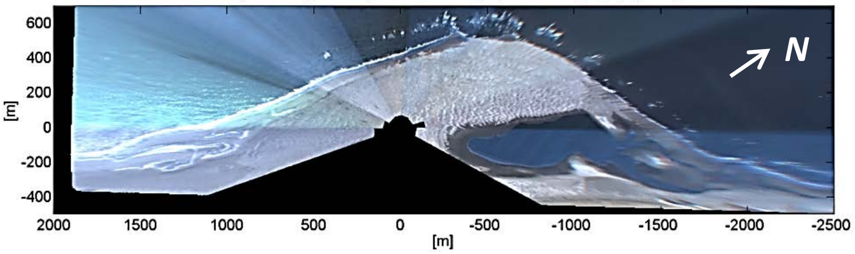


Fig. 1. Top view of the Sand Motor mega-nourishment, as viewed by the Argus video station (merged image of eight rectified snapshot images).

The Sand Motor is an innovative way of nourishing which is expected to protect the coast for approximately 20 years, which is much longer than regular small-scale nourishments (Stive et al., 2013). An important goal of the Sand Motor is to increase the sand supply towards the dunes in the surrounding area, because these dunes function as natural flood protection for the densely populated hinterland.

One of the important aspects to determine in this pilot project is how the wind driven sand transport at the Sand Motor will exactly affect dune formation, not only in quantity but also in its timing as well as spatial variation. The latter is expected because of the particular design of the mega nourishment, with both a lagoon and a lake (Figure 5).

The uncertainty about these issues is related to the difficulties in modelling and measuring the wind driven sand transport process on beaches. When studying aeolian transport on beaches, there is often limited correspondence between transport rates derived from predictive equations and from sand traps or transport sensors in the field (e.g. Barchyn et al., 2014; Sherman et al., 1998). Uncertainties also relate to the problem of up-scaling such process-scale knowledge to time- and space-varying sand supply over time spans of several years up to decades.

This study aims at improving insights in this upscaling issue by mapping aeolian activity at the Sand Motor at multiple scales. Ranging from single sand transport events to erosion/deposition patterns developing over many years. We hypothesize that the relation between ‘aeolian activity at the Sand Motor’ and ‘sediment supply towards the dunes’, is not only a function of wind conditions, but also of the morphology of the Sand Motor and surface conditions that may limit the availability of sand for transport by wind.

In the following section we summarize the data collection directly related to the aeolian transport study, and next we will present some first findings regarding aeolian activity across the Sand Motor.

Methods and data

Argus video imagery plays a central role in the mapping of aeolian activity at the Sand Motor. An Argus system is an automated video station equipped with several cameras, taking pictures of the beach and nearshore zone. Data obtained by Argus systems have already successfully been used to study features in the nearshore zone as well as intertidal bathymetry (Holman and Stanley, 2007). This study will focus on the use of Argus imagery in studying aeolian processes, cf. Delgado-Fernandez and Davidson-Arnott (2011) who applied a video-based technique similar to the Argus system to study aeolian sediment transport at meso-scales.

In February 2013, an Argus video monitoring system consisting of 8 cameras, covering the seaward side of the mega nourishment and the lagoon area, was mounted on a 40 meter high tower in the middle of the Sand Motor. These cameras are taking snapshot and time-exposure images semi-hourly during day-light hours, and cover a large part of the Sand Motor surface (Figure 1). These images are forming a unique, high temporal resolution data set, covering both a long time period (i.e. several years) and a large spatial scale (i.e. the total Sand Motor area).

The video images are used for two main purposes. Firstly, to locate and track aeolian features (e.g. streamers, bedforms) and to quantify their properties, such as migration speed or transport direction. These data will provide information on aeolian activity at (i) the event-scale, i.e. a wind-driven transport event of several hours to several days duration, and (ii) at the scale of series of subsequent events over e.g. months to years (depending on prevailing wind climatology). Subsequent events together will result in net erosion and deposition patterns varying over time and in space. These patterns will be derived from bathymetric and topographic surveys that are conducted every two months (by 'Shore Monitoring & Research'), and LiDAR flights covering the beach and dune area every six months. In addition, complementary surveys of the seaward side of the dunes are made using a terrestrial laser scanner, and transects are surveyed across the newly developing foredune using RTK-GPS.

Secondly, the Argus images also provide some level of information about the variation in surface characteristics of the Sand Motor over time and space ('dry' vs 'moist' surface, sand vs. shell pavement), which will be validated by ground truth samples. Wind data is continuously collected by a weather station mounted at the tower.

To quantify the aeolian transport that is observed to occur on the Argus imagery (so event-scale transport rates), transport equations will be used, for which parameter settings will be calibrated based on Argus-observed transport activity and surface characteristics. Also, sand transport measurements will be done using laser-based particle counters (Wenglors) to support image interpretation regarding aeolian activity as well as to verify the calculated transport rates.

Finally, in this paper we present some first order estimates of annual scale transport rates, based on the topographic surveys of August 3, 2011; July 27, 2012; July 4 2013; and July 2, 2014. These values were derived from deposition occurring in the lake area at the Sand Motor (see Figure 5). First, the elevation data in this area was linearly interpolated to a 2x2m grid. Next, for all years the volume increase since August 3, 2011 was calculated for all grid cells on the westerly side of the lake area where elevation change exceeded +0.2m.

Transport rates were then derived by dividing the approximately annual volume increase by the length of the windward boundary. As a thorough analysis of contributing wind events is still to be made, a minimum and maximum length of this boundary was used of 400 m and 600 m, respectively.

Preliminary results

Event scale aeolian transport

A first, qualitative interpretation of Argus image time series supports the hypothesis that the relation between 'aeolian activity at the Sand Motor' and 'sediment supply towards the dunes', is not only a function of wind conditions. During single transport events it has been repeatedly observed that the lagoon traps sediments, (Figure 2), and that the prevailing wind field apparently does not initiate similar aeolian transport on the beach located on the landward side of the lagoon, (Figure 2).

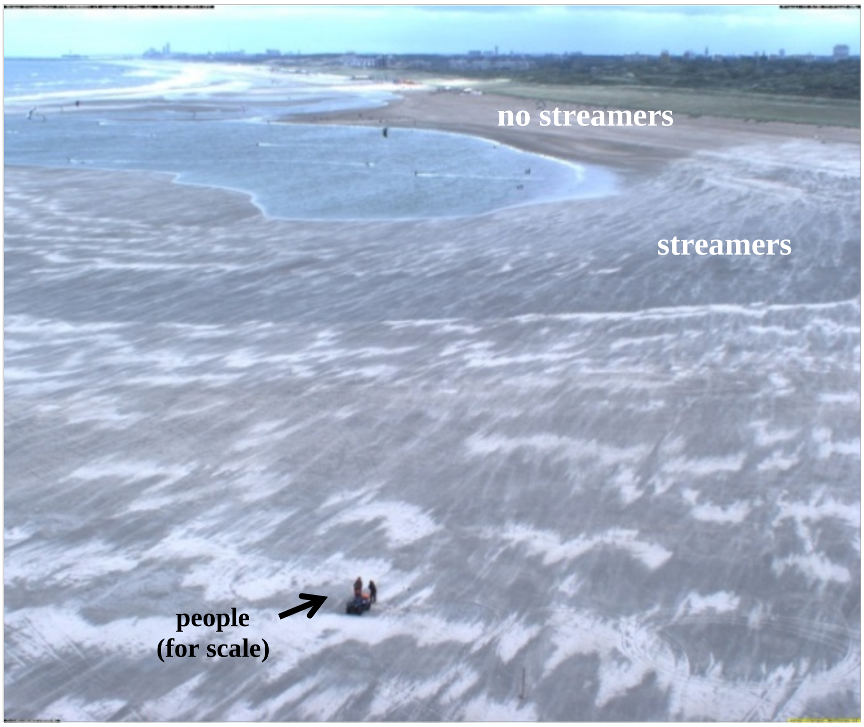


Fig. 2. Northeast view from Argus video station, showing an example of aeolian activity (aeolian streamers and bed forms). Note that the lagoon traps a large part of the aeolian transport.

First steps have been taken towards quantifying such time- and space varying transport patterns across the Sand Motor from the Argus imagery, by mapping bedform migration speed and direction (Figure 3). Relating these to time-varying wind conditions and surface properties, will provide insight into the relative importance of these factors over a specific event.

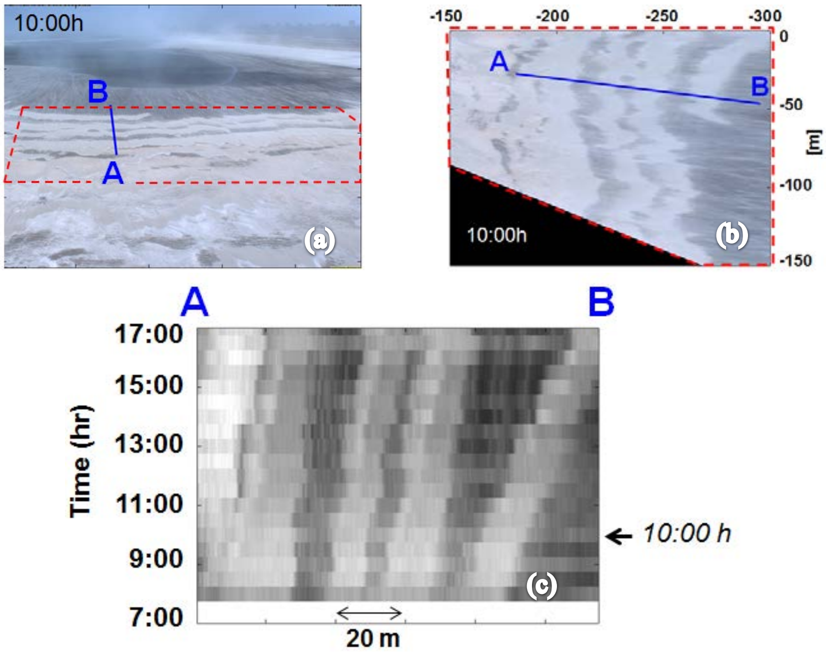


Fig. 3. Tracking aeolian bedforms using Argus video imagery. (a) Oblique snapshot image; (b) Image rectification of area in red dashed box in a; (c) Time stack of normalized pixel intensities along line A-B. Bed forms appear as brighter areas, and are shown to migrate at a rate of order m/hr.

Aeolian transport at the scale of month to years

From the three years of bi-monthly topographic surveys, an infill of the lagoon from the westward side can be observed. Given our qualitative observations from the Argus image time series, this infill will at least partly have an aeolian origin (Figure 4). An infill that for certain is completely of aeolian origin, is that occurring in the small lake in the center of the Sand Motor (Figure 5).

The surface depression around the lake, and the lake itself, act as a sand trap for aeolian sand transport across the Sand Motor. Annual difference plots clearly demonstrate that considerable accretion occurred on the westerly side of the

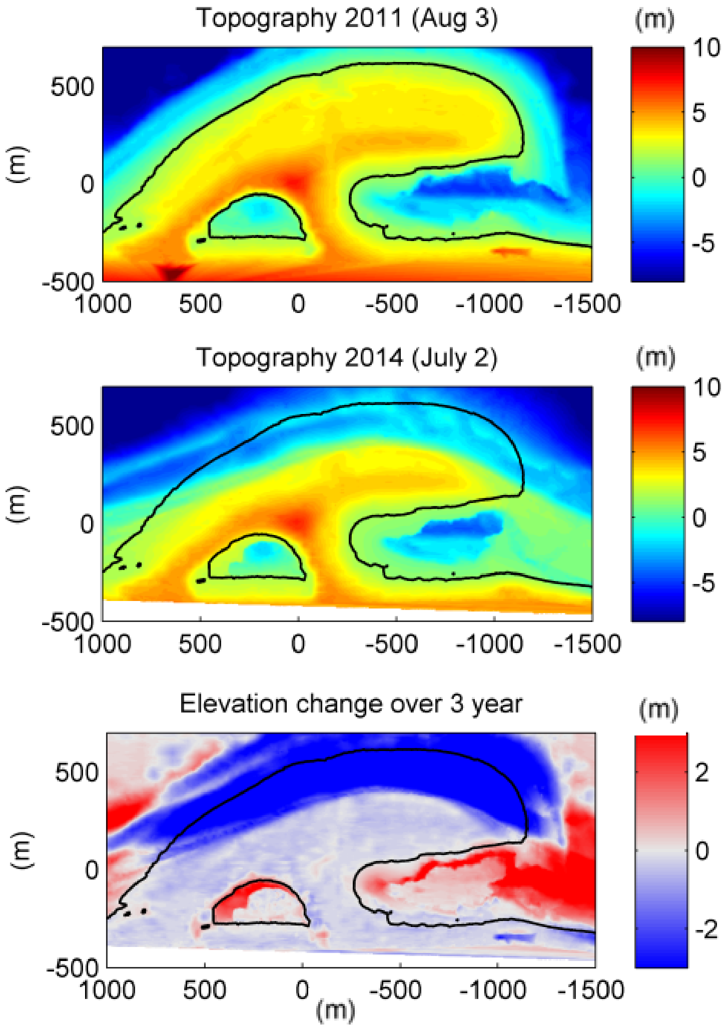
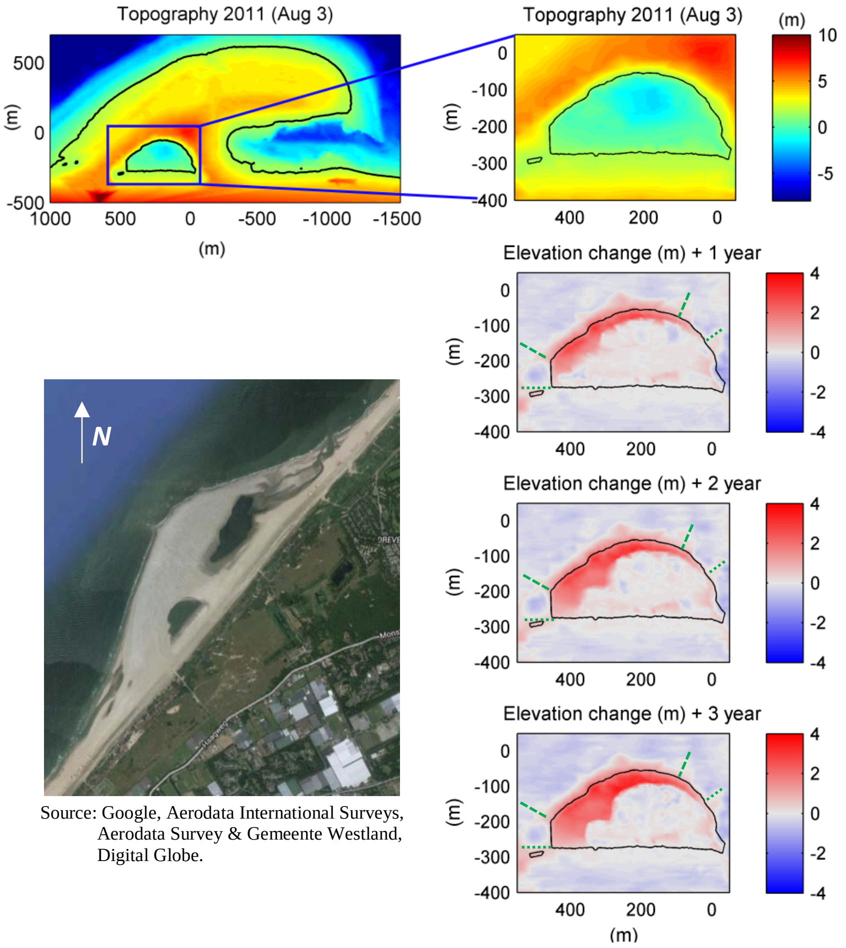


Fig. 4. Topographic change (in m) on the Sand Motor (August 2011- July 2014); contour line at +1.5m. The semi-circular depression near x=0-500m, contains a small lake.



Source: Google, Aerodata International Surveys, Aerodata Survey & Gemeente Westland, Digital Globe.

Fig. 5. Elevation change near the lake due to aeolian infill. Green dashed and dotted lines in three lower right-hand panels indicate minimum resp. maximum extent of the windward boundary for estimating aeolian transport rates.

lake. As the Dutch wind climate is dominated by winds from southwesterly directions (most frequent), and strongest winds from northwesterly directions (Wieringa and Rijkoort, 1983), the volume of sediment deposited in this area is considered a good first order estimate of the magnitude of total aeolian transport rates across the Sand Motor.

Over the period August 2011 to July 2014, the aeolian deposition decreased from an initial 47.10^3 m^3/yr in the first one year period, to 11.10^3 m^3/yr in the last one year period (Table 1). When we take into account that the curved line defining the windward boundary of this accretion area is between 400 and 600 m long, depending on how far this boundary is extended sideways (Figure 5), this amounts to annual aeolian transport rates that decreased from an initial 78-117 m^3/m/yr to 18-28 m^3/m/yr in 2013/2014 (Table 1).

Table 1. Aeolian deposition in the lake area 2011 - 2014

Survey date	**Cumulative deposition since Aug 3, 2011** **10^3 m^3**	**Deposition since previous survey** **10^3 m^3**	**Approximate transport rate into the lake area , since previous survey** **m^3/m**
2012 (July 27)	47	47	78-118*
2013 (July 4)	62	15	25-38*
2014 (July2)	73	11	18-28*

* range of transport rates depends on presumed length of windward boundary

Discussion

The annual volume increase in the foredunes along a more northerly section of the Dutch coast (‘Noord-Holland’), typically is in the range of 5-20 m^3/m/yr in non storm surge erosion years (Keijsers et al, 2014). Since these rates relate to years without storm surge erosion of the dune, these values are considered a reasonable reference value for what are normal annual aeolian transport rates along the Dutch west coast. From this perspective, the aeolian transport amounts at the mega nourishment seem to have been far above ‘normal’ initially, but are now closing in on more normal amounts for the Dutch coast.

Explanations for the observed trend should be found in a combination of the following three main factors: (i) changes in the surface properties of the Sand Motor, (ii) changes in the morphology of the Sand Motor, (iii) variations in weather conditions.

The first factor involves possible changes in the availability of sand for transportation by wind. For instance, progressive coarsening over time of the top layer of sand at the subaerial part of the Sand Motor may have occurred. In addition, since the Sand Motor consists of dredged seabed material with a notable amount of shells in it, progressive armoring of the surface by shells and shell fragments may have occurred (Van der Wal, 1998a, 1998b), or the number of locations where such conditions developed may have increased. Similarly, changes in local crust formation may have occurred. Note that in October 2014, we saw in the field that the top layer of the Sand Motor is still quite actively eroding during stormy conditions, as evidenced by the differential bed erosion going on around shells (Figure 6). Shells and shell fragments were also observed to be moved by the wind during those conditions. This, however, is only an anecdotic observation and more thorough analyses are still to be done.

Fig. 6. Aeolian erosion marks developing on the surface of the Sand Motor mega nourishment (see pencil for scale) on October 7, 2014. Wind is blowing from the right.

The second factor involves both large scale and smaller scale morphologic characteristics that can affect the size and location of the source areas for aeolian transport. At the large scale, the overall subaerial shape of the Sand Motor area has been narrowing in the cross-shore direction and stretching in the longshore direction (Figure 4). At a smaller scale, changes in prevailing morphology of the intertidal beach may have occurred over time in relation to these larger scale developments. For instance, the frequency of occurrence and character of ridge-runnel topography may have changed with the evolving large scale morphology, which can affect the aeolian export of sand from the intertidal beach (e.g. Anthony et al., 2009). Also, trends in the frequency of occurrence of beach cliffs, that have been observed to develop on the NW-N side of the Sand Motor, may have occurred (Figure 7). The Argus image time series can be used to analyze and quantify the possible trends in intertidal morphology as source area for aeolian transport.

The third factor deals with inter-annual variations in wind directions, wind speed, and precipitation, which, combined with the other two factors, determine the number and magnitude of aeolian transport events.

Fig**.** 7**.** Beach cliff on NW side of the Sand Motor mega nourishment (photo October 8, 2014).

Conclusion

Preliminary results indicate a decrease in aeolian sediment transport rates at the Sand Motor mega nourishment since 2011/2012. Additional research is needed to further substantiate, and understand, these findings. For instance, the Argus video data will be used in future work to identify and quantify the transport events that actually caused the aeolian deposition in the lake area. Also, Argus video based analyses of changes in source area characteristics are foreseen, as well as an analysis of volume changes in the newly developing foredune landward of the mega nourishment. Here we expect to see an influence of the location of the lagoon and lake on spatial variation in sand supply to these foredunes.

Acknowledgements

This research is part of the NatureCoast program, funded by the Dutch Technology Foundation STW, which is part of Netherlands Organization for Scientific Research. We acknowledge Rijkswaterstaat for making available the Argus images and topographic data collected by ‘SHORE Monitoring & Research’, and Deltares for providing the Argus tools.

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