MONITORING AEOLIAN ACTIVITY DURING A STORM EVENT USING A VIDEO SYSTEM

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Abstract

Aeolian sand transport was assessed from an Argus camera system located on a macro-tidal beach along the Belgian coast over a period of 4 days covering a storm surge. Over the study period, observed sand transport event occurred for 9.5% of the time when strong high oblique onshore wind (9.8m/s) combined with a water level below 3.75m TAW moved sand to the beach. Measured post-storm topographic profiles indicated an accretion on the total beach upper beach of 0.70m³/m, which was in agreement with the estimated potential sand supply of 0.91m³/m for the observed sand transport event and expected night transport events. Thus, there was a narrow temporal window in which sediment can be supplied to the beach before and after the storm surge. Also, the study highlights that the presence of berm with a relative height of 3m segments sediment transfer to the backshore.

Key words: beach morphology, erosion/deposition, potential sand supply, macro-tidal, Belgian coast

1. Introduction

Aeolian sand transport is a response to a physically complex series of processes associated with wind (Sherman and Hotta, 1990). Aeolian sand transport rates across the beach system are highly variable in time and space due to changing wind condition. Also, the presence of a broad suite of environmental factors such as surface moisture, the presence of surface lags and crust, grain size, and surface roughness acting at different spatial and temporal scales control aeolian sand transport rates (*e.g.* Gares, 1988, Jackson and Cooper, 1999, Davidson-Arnott and Bauer, 2009). Most of these supply limiting factors are dependent on the morphology of the intertidal zone and the backshore. The beach morphology tends to be viewed as a static transport surface (Houser, 2008), however it often subject to rapid changes, especially during a storm.

The supply limiting factors make it difficult to measure aeolian activity with traditional sand traps and/or saltation probes on the field. In addition, observations of aeolian sand transport in coastal areas have focused on short-term (<1 day) field experiments, providing knowledge based on 'snapshot'. However, the recent advance in remote sensing techniques to measure aeolian activity at the beach has made possible the direct observation of sand transport over a longer time span. Video-based technique has been recently used to study aeolian sand transport in coastal environment. Lynch *et al.* (2008) used it to gauge sediment transport patterns to dune development over a one-month. Also, Delgado-Fernandez and Davidson-Arnott (2011) used a video system to quantify meso-scale sand inputs to the dunes. In this study, we propose the utilization of an Argus video system to monitor aeolian activity under an entire storm event with a high sample frequency.

The Argus video program, developed at the Coastal Imaging Lab, Oregon State University, involves the installation of automated camera stations at sites of scientific and coastal management interests (Holman *et al.*, 1993). A station is typically composed of several cameras, covering the area of interest in the field of view with a coverage of several kilometers. It captures images of the beach and nearshore zones, allowing to study successfully morphological features that are present on the beach (Holman and Stanley, 2007). This study uses Argus image to locate and track aeolian features such as sand strips, transient and mobile bedforms commonly observed during high energy sand transport events. Therefore, the aim of this study is to monitor aeolian sand transport during an entire storm event on a macro-tidal beach at Mariakerke (Belgium) based on camera images.

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2. Study site

The beach monitoring was carried out at Mariakerke (section 104) located on the west part of the Belgian coast (Figure 1). This coastal section is orientated SW-NE and quite homogeneous in the longshore direction. The dissipative beach is flat, exceeded a width of 200m and linked landward by a dyke. In the backshore, the beach is characterized by a low slope (5°) with an artificial berm built after beach nourishments at a distance around 40-50m from the dyke. Other human interferences in Mariakerke include a groyne field. The beach sediment consists of medium sand (D₅₀: 310µm) due to the nourishments in this zone.

The beach is characterized by macro-tidal regime ranging from 3.5 m at neap tide to 5 m at spring tide. Prevailing winds come from SW and are characterized by speeds of 3-8m/s (Figure 1C). However, high wind speeds (> 10m/s) are coming from WSW to NW; and their strongest period is between November and February. Onshore high wind speed events are associated with SW-W-NW atmospheric circulations which could be the most threatening conditions for the occurrence of storm surge (Montreuil *et al.*, 2016). Storm surges are recorded at least one time per year when water level and onshore wave height could reach 5m TAW (Belgium Ordnance Datum) and 3m respectively (Haerens *et al.*, 2012).



Figure 1. A) Map of the study site with the surveyed cross-shore profiles (black line); B) Location of study area; C) Annual wind rose.

3. Methods

3.1 Argus data

An Argus monitoring system equipped with six cameras looking in different directions, is installed on a 44m high building in Mariakerke (Figure 1 and Figure 2B). It is in operation at the site since June 2014. The Argus system takes semi-hourly a snapshot image, a single image frame of the first of 10-minute image recorded, for each camera at 2 Hz. They are automatically saved during day light hours and operate through all weather conditions.

Camera 2 has a good view from the intertidal zone to the backshore so that it was used to identify aeolian transport process (Figure 2). Transport could be observed in the form of sand strips on the dry beach. These transient sedimentary bedforms occur on beaches where surface moisture, roughness elements vary in space and time (Nield *et al.*, 2011); and move relatively slowly. They appear on the camera images as sequential stripes of light coloured sand dry sand and dark coloured sand of moist beach

surface (Figure 2A, B). Here, the snapshot images were used to locate and track the displacement of the sand strips by switching back and forth between the consecutive images. In addition, the quantification of their properties such as displacement speed was carried out by analyzing the pixel intensity values along two lines perpendicular to the sand strips extracted from the successive images. To facilitate image processing and visualization, the colour snapshots were converted to grey images.



Figure 2. A) Example of plan view of rectified and B) merged snapshots from the six cameras. Shaded lines are the field of view of camera 2; C) Argus camera system at the study site.

3.2 Field-based data

Complementary data of three cross-shore profiles of the beach carried out using RTK-GPS system on 14th January (before the storm) and on 18th January 2016 (after storm) were used to determine morphological and volumetric changes (Figure 1A). The cross-shore profiles were distant of around 150m. They extended from the dyke to the low water line on 14th January and to the elevation of 3.5m TAW on 18th January. In addition, wind records were collected from the Ostende airport, the closest weather station to the study site (Figure 1A). It makes sub-hourly measurements of wind speed and direction (at fixed point every 00:00, 00:20, 00:50 o'clock time). The wind speed and direction have a resolution of 0.1 m/s and 10° respectively. The anemometer is located at 4m above the ground level. Atmospheric and precipitation data are not available at this weather station so that they were acquired from Zeebrugge weather station located at 25km from the study site. These were assumed to be representative of the conditions at the study site. Furthermore, 5-minute water level records were collected from the tide gauge in Ostende harbor, and 30-minture onshore wave height records from the wave buoy at Raversijde.

3.3. Calculation of potential sediment supply

The wind speed measurements at the station were standardized at 10m high by calculating:

$$U_c = U_m \times \frac{\ln(\frac{H_c}{Z})}{\ln(\frac{H_4}{Z})}$$
(1)

Where H_c is the height of the wind speed to be calculated at 10m, Hm is the height of the measured wind speed. U_c and U_m are the calculated and measured wind speed respectively. The roughness length (z) was considered to be 0.0002m. Potential sediment transport to the dry beach was predicted using Hsu equation (1974) based on field measurements of the relationship with wind speed:

$$q = 1.16 \times 10^{-5} * U^3 \tag{2}$$

Where U is the wind speed in m/s, q is the instantaneous rate of sand transport (kg/m/s). The hourly average wind speed recorded at Ostende airport was calculated and used as the input into the formula to determine the potential of wind to transport sediment in the direction of wind sector. Then, it was modified by the hourly average angle of wind approach (α) relative to the shore normal in order to obtain a magnitude based on the potential of wind to deliver sediment (Davidson-Arnott and Law, 1996).

$$qi = q \times \cos(\alpha) \tag{3}$$

Where q_i is the potential transport to the beach per unit alongshore distance (kg/m/s). Finally, total sand input to the beach for a wind event (Q, kg/m) was predicted by summation of all calculated hourly transport rates:

$$Q = \sum_{i=1}^{N} q_i \times 3600 \tag{4}$$

Where q_i is the predicted instantaneous sand transport rate for hour I, and N is the total number of hours in the event.

4. Results

4.1. Forcing factor conditions

During the study period, a storm occurred on 14-15th January 2016 when a depression travelling the North Sea basin characterized by an atmospheric pressure of 1000hPa (Figure 3). The wind exceeded 10m/s from 14th January at 12pm to 15th January at 8pm. It reached a maximum of 21.4m/s on the first evening (Figure 3). Wind was blowing from 260° (W direction) at the beginning of the event. Rapidly, it was oriented between 300° and 330° (WNW direction), corresponding to an oblique onshore wind from shore normal. No precipitation was recorded during the storm. Regarding the hydrodynamics, the most energetic period of the storm took place on 15th January around 3am when the water level reached 5.3m TAW and the onshore wave height (Hs) was of 3.5m. After the storm, the wind drastically dropped its speed and was still blowing from W-WNW direction. Also, wave heights progressively decreased to reach typical values of about 1m from 17th January morning.

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Figure 3. Time series of atmospheric pressure, wind speed and direction, water level, onshore wave height. Red rectangular indicates the period of the storm event exceeded 10m/s and the brown lines correspond to the field topographic surveys.

4.2. Observed sand transports during the storm

A total of 95 Argus snapshot images from 14th January to 18th January 2016 were acquired at daylight from 7:30am to 4:30pm and analyzed. There was not any gap in the time series. During the study period, aeolian sand activity was only observed on 14th January from 9:30am to 1:30pm (Figure 4A). Sand transport began in response to an increase of wind speed above 8m/s and a water level below 3.75m TAW. The wind was characterized by an average wind speed of 10.2m/s with a maximum of 13.6m/s and oriented 260° (W) most of the time of the observed transport event. Images show a large spatial variability of aeolian sand strips on the beach. These bedforms were present on the backshore and on the intertidal zone at the seaward of the berm. They mainly displaced in highly oblique direction to the beach and thus orientated perpendicular to the coming wind. No sand strip was on the top of the berm where darker sand appeared. Thus, it was likely that higher surface moisture content preventing sand transport. Interestingly, this band of no transport seems to be relatively uniform along the berm. Although the wind conditions were favourable for sand transport on the beach in the afternoon on 14th January (i.e. from 2-4:30pm) and in the daylight on 15th January, no aeolian activity occurred on the beach because of the water inundation before and after the peak of the storm limiting the fetch distance (Figure 4A). The water level reached 4.97m TAW over this period.



Figure 4. Time series of A) snapshot images from camera 2 of the Argus system during no transport activity on 14th January at 8:30am; the observed sand transport event on 14th January 2016; and the occurrence of beach inundations on 14th January at 2:30pm; B) Extraction of the image pixel intensities (from deviation from average intensity). Note the x-axes are not the same.

Figure 4B displays the pixel intensity of the two lines extracted on the backshore and on the upper part of the intertidal zone over the observed transport event. No pixel intensity analysis was performed for the

image at 10:30am because of the large variation of solar radiation at that time. Along the lines, a peak represents dry sediment area, while a low is where more moist sediment is present. Active transport can be identified by the shift of the peak on the successive images. For both lines, there is considerable spatial variation in peak of pixel intensity associated with the sand strips. Along the extracted backshore line, four peaks are observed from 11:30am to 1:30pm. They were characterized by a relative constant width over time. The sand strips progressively migrated with an average of 25.1pixel/hour and with an increase up to 30pixel/hour between 12:30am-1.30pm. A large patch composed of several peaks and two other smaller peaks are depicted from the extracted intertidal zone line, located at the seaward side of the berm. Their displacements were slightly slower than on the backshore since they migrated around 20pixel/hr. Over the last hour, faster migration of the sand strips occurred for both the backshore and upper intertidal zone, caused by an increase of the wind speed. Therefore, the characteristics, location, and mobility of the sand strips are not constant on the beach, which seem to be here controlled by wind condition, moisture content and beach topography.

4.3. Measured erosion and deposition over the storm

Before the storm (14th January 2016), the shape of the three cross-shore profiles was typical of a nourished beach with a bounded berm (Figure 6). For instance, profile 104a featured a berm of a height of 7.5m TAW, corresponding to a height around 3m relative to the upper part of the intertidal zone, which extended to a distance of 55m from the dyke. This means that sand was available on the upper part of the beach. The intertidal beach was relatively flat and featureless. After the storm on 18th January, profiles 104a, 104b, and 104c did not show any significant changes of the backshore (i.e. zone above 6.89m TAW) except that the windward of the berm was eroded due to wave scarping. While the upper-part of the intertidal beach was stable or slightly gained sand. Thus, sand was removed from the berm and then was deposited to the intertidal beach during the storm.



Figure 6. A) Cross-shore topographic profiles of P104a, P104b, P104c. From the top to the bottom of the y-axes, dashed lines correspond to the elevation datum of 6.89m TAW, the high water level line (4.39m TAW) and the elevation of 3.5m TAW; B) zoom of the upper part of the profiles.

Calculations of sediment budget performed for the cross-shore profiles indicated that the quantity of sediment lost through erosion of the backshore for profiles 104a and 104b (respectively -2.6 and -0.2 m³/m) was counterbalanced by a sediment gain on the upper intertidal zone (respectively 0.9 and 0.1 m³/m) (Table

1). However, the results obtained for profile P104c showed that the entire beach profile underwent accretion of $4.31m^3/m$. By averaging volume changes of the three profiles, a small sediment gain of $0.70m^3/m$ occurred, corresponding to an increase of elevation around 0.6cm across the beach.

	Volume changes (m ³ /m)				
	104a	104b	104c		
Backshore (from dyke to 6.89m TAW)	-2.62	-0.18	1.85		
Upper intertidal beach (from 6.89m to 3.5m TAW)	0.92	0.08	2.45		
Total	-1.70	-0.50	4.31		

Table 1. Measured sediment volume changes per beach zones for the cross-shore profiles.

4.4. Sediment input predicted over the storm

In order to obtain an approximation of the amount of sand delivered to the beach, the predicted rate of aeolian sediment transport (Q) was calculated based on records of wind speed and direction. Table 2 summarizes the characteristics of the transport events resulting in potential sediment supply. It includes the observed sand transport event identified on the snapshot images on 14th January which was associated with a wind speed above 9.8m/s (maximum 13.6m/s) and a direction highly oblique to the shore normal lasting for 4hours. The water level ranged from 0.14-3.75m TAW. For this event, predicted sand transport was 103kg/m or 0.04m³/m, assuming a sediment density of 2650kg/m³ (Bagnold, 1941). The predicted values are much lower than the measured deposition of 0.7m³/m. High wind speed and a shift of wind direction towards 280° (oblique onshore) favouring sand transport to the beach associated with a water level below 3.75m TAW occurred at nightfall on 14th January and after the peak of the storm on 15th January at 6-7am. Thus, it is reasonable to expect that there was a narrow temporal window in which sediment could have been delivered. In the case of observed sand transport event and expected night transport, the predicted sand transport of 2433kg/m equivalent to 0.91m³/m which overestimates slightly the measured deposition.

Table 2. Characteristics of the aeolian transport events resulting in sediment supply. U=mean wind speed (m/s); Umax=wind speed peak (m/s); Ud=mean wind direction (°); α=angle of wind approach relative to shore normal; WD=duration of transport event (h); Q= total predicted sediment transport (kg/m).

	Event	U	Umax	Ud	α	WD	Q
	Observed sand transport event	9.8	13.6	260	60 (high oblique onshore)	4	103
	Observed sand transport event + expected night transport	15.3	21.4	280	40 (oblique onshore)	14	2433

5. Discussion

A total of 95 Argus images were acquired and analyzed for four days from 14th-18th January 2016 when a storm surge occurred. On 14th January at 9am, westerly wind started blowing over the threshold for sediment transport of 7m/s based on instantaneous sand transport measurements undertaken at the study site (Strypsteen, *pers. comm.*). It exceeded 10m/s from 14th January at 12pm to 15th January at 8pm, resulting in a wind duration of 32hours. This combined with high tide generated a surge of 0.7m on 15th January at 3am. Observed sand transport event toward the beach was depicted on 9 images taken on 14th January from 9:30 to 13:30am, corresponding to 9.5% of the time over the study period.

The impact of this storm surge was limited on the backshore with small scarping berm. The eroded sand was locally deposited to the upper part of the intertidal beach, and thus still present in the beach system. It is likely that the berm reduced wave energy on the backshore and thus preventing erosion. The adjustment principle of the equilibrium profile between the dry beach/dune and the upper tidal beach zones previously

reported (Dean, 1991) functions correctly at Mariakerke. The overall morphology of the beach, thus, must have approximated an equilibrium shape on the temporal scale of the storm event. A net gain of sand of +0.7m³/m was measured for the total beach. This was slightly lower but in in the same order of magnitude as the estimated potential sand supply of 0.91m³/m which considered both the observed transport event on the snapshot images and the expected night transport based on an onshore wind above threshold of movement and water level below 3.75m TAW. During the first stage of the storm, the wind speed ranged from 8.2 to 13.5m/s blowing highly obliquely from the W coinciding with a low tide, yielding a long fetch distance on the midday of 14th January, favored sediment transport to the upper beach. High water level was combined with strong waves causing the inundation of the beach during the peak of the storm from 14th January at 2:30pm. This likely resulted in a complete shut-down of sediment transport and partial erosion of the backshore and berm. Although no image was recorded over-night after the peak of the storm, strong oblique onshore wind from WNW direction coupled with a water level below 3.75m TAW occurred and could have delivered sediment to the upper beach. Previous studies suggest that sediment input to the beach system is mainly governed by trade-offs between the angle of wind approach, fetch distances, surface moisture content and event duration (Bauer et al., 2012, Delgado-Fernandez and Davidson-Arnott, 2011). Thus, strong oblique onshore winds may drive to a substantial amount of transport across the beach even with a high surface moisture content because of the unlimited long fetch distances. While a decrease of sediment transport could occur under strong onshore wind due to the combined effect of high surface moisture content and short fetch distances. Depending on the beach width, a strong onshore wind may even cause wave scarping of the beach-dune instead of aeolian sediment supply from the intertidal each because of storm surge and wave run-up (Delgado-Fernandez, 2011).

As indicator of aeolian activity, sand strips appeared on the images as bands of light coloured sand on dark sand and generated zebra-like patterns on the beach. Sand strips were present on the dry beach, and were oriented perpendicular to the wind direction. The results suggest that the sand strips migrated faster on the backshore than on the upper intertidal zone. No transport, however, took place on the top of the berm where high surface moisture content limited the entrainment of sediment transport. Another supply limiting factors may be lags of coarse sand and shells and also surface crust development commonly observed there during field visits. Also, the berm of a height around 3m relative to the upper intertidal zone might have disturbed airflow by leading to a significant deceleration of the leeward side of its crest which in turn affected sediment transport as reported in previous studies (Short and Hesp, 1982, Bauer et al., 2012). Here, the aeolian sediment transport pathway was segmented by the berm. Therefore, there was a spatial variability of sand strip formation and migration on the beach. Nield (2011) modeled sand strip formation and found that they become self-organize into a similar pattern regardless of initial surface moisture and sedimentation relationships. Although our understanding on the formation and mobility of sand strips is limited, previous studies have reported that their dynamic behaviour result from feedback between with aeolian sand transport, surface moisture patterns, and bedform migration (Baas, 2007, Nield et al., 2010).

This study used an accessible technique of Argus camera system for monitoring aeolian activity on the beach during a storm event. It offers a number of advantages such as providing a high resolution data set, and being direct observation of transport rather than relying on assessment from morphological evidence (Delgado-Fernandez and Davidson-Arnott, 2011). The use of video remote sensing is a powerful system to get a better insight of the aeolian dynamics from short (hour) to long (years) time scales, which coupled with time series of wind and water level records and beach topographic monitoring would allow to develop appropriate tool for decision-making for coastal managers and planners.

Conclusion

This study monitored aeolian activity on a macro-tidal beach for a period of four days when a storm surge occurred on 14th -15th January 2016. A camera-based technique based on Argus system of high frequency image records was used to locate and track sand transport across the beach. Over the study period, wind exceeded 10m/s for 32hours, reaching a maximum of 21.4m/s. It was oriented W-WNW, corresponding to an oblique onshore wind relative to the shore normal. The water level ranged from 0.56m-5.27m TAW at low and high tide respectively; and the peak of wave height was 3.6m.Over the study period, observed sand transport event occurred for 9.5% of the time. This happened before the storm when strong high oblique

onshore wind (9.8m/s) combined with a water level below 3.75m TAW favoured sand movement to the beach. During the storm surge, sand transport was shut down due to the inundation of the beach. Then, a strong oblique onshore wind was still blowing at low tide which probably led to sand transport before a decrease of wind speed below the threshold of movement. A net gain of sand of $+0.7\text{m}^3/\text{m}$ was measured for the total beach, which was in the same order of magnitude as the estimated potential sand supply of $0.91\text{m}^3/\text{m}$ for the observed sand transport event and expected night transport events. Therefore, the conditions and time window of occurrence of the wind, water level and waves favoured a positive volumetric change of the beach. Also, beach morphology is also important for the intertidal beach to backshore sediment transfer. The results indicated that the berm of a relative height of 3m located on the backshore influenced the development of sand strips by segmenting their sediment transport pathway. Video imagery coupled with wind and water level records and beach topographic monitoring could be a powerful approach to get a comprehensive view of the aeolian dynamics controlling beach morphology.

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References

Bagnold, R.A. 1941. The Physics of blown sand and desert dunes. Methuen.

- Baas, A.C.W., 2007. Complex systems in aeolian geomorphology, Geomorphology, 91: 311-331.
- Bauer,B.O., Davidson-Arnott, R.G.D., Walker, I.J., Hesp, P.A. and Ollerhead , J., 2012. Wind direction and complex sediment transport response across a beach-dune system, *Earth Surface Processes and Landforms*, 37 (15): 1661-1677.
- Davidson-Arnott, R.G. D. and Bauer, B.O., 2009. Aeolian sediment transport on a beach: Thresholds, intermittency, and high frequency variability, *Geomorphology*, 105: 117-126.
- Davidson-Arnott, R. G. D. and Law, M. N., 1996. Measurement and Prediction of Long-Term Sediment Supply to Coastal Foredunes, *Journal of Coastal Research*, 12(3): 654-663.
- Dean, R.G., 1991. Equilibrium beach profiles: characteristics and applications, Journal of Coastal Research, 7: 53-84.
- Delgado-Fernandez, I., 2011. Meso-scale modelling of Aeolian sediment input to coastal dunes, *Geomorphology*, 130: 230-243.
- Delgado-Fernandez, I. and Davidson-Arnott, R., 2011. Meso-scale aeolian sediment input to coastal dunes: The nature of aeolian transport events, *Geomorphology*, 126: 217-232.
- Gares, P.A., 1988. Factors affecting eaolian sediment transport in beach and dune environments. *Journal of Coastal Research*, SI3: 121-126.
- Haerens, P., Bolle, A., Trouw, K. and Houthuys, R., 2012. Definition of storm thresholds for significant morphological change of the sandy beaches along the Belgian coastline. *Geomorphology*, 143: 104-117.
- Holman, R. A. and Stanley, J., 2007. The history and technical capabilities of Argus. Coastal Engineering, 54, 477-491. Holman, R. A., Sallenger, A.H., Lippmann, T.C., and Haines, J.W., 1993. The application of video image processing to

the study of nearshore processes, *Oceanography*, 6: 3.

- Houser, C., 2008. Synchronization of transport and supply in beach-dune interaction, *Progress in Physical Geography*, 33(6): 733-746.
- Hsu, S.A., 1974. *Computing aeolian sand transport from routine weather data*, Proc. 14th Coastal Engineering Conference, ASCE.
- Jackson, D.W.T. and Cooper, J.A.G., 1999. Beach fetch distance and aeolian sediment transport, *Sedimentology*, 46: 517-522.
- Lynch, K., Jackson, D.W.T. and Cooper J.A.G., 2008. Aeolian fetch distance and secondary airflow effects: the influence of micro-scale variables on meso-scale foredune development. *Earth Surface Processes and Landforms*, 33:991-1005.
- Montreuil, A-L. Elyahyioui, J., Chen, M., 2016. Effect of Large-Scale Atmospheric Circulation and Wind on storm surge occurrence, *Journal of Coastal Research*, 75(2):755-760.
- Nield, J., M., 2011. Surface moisture-induced feedback in aeolian environments, Geology, 39 (10): 915-918.
- Nield, J.M., Wiggs, G.F.S. and Squirrel, R., S., 2010. Aeolian sand strip mobility and protodune development on a drying beach: examining surface moisture and surface roughness patterns measured by terrestrial laser scanning, *Earth Surface Processes and Landforms*, 38: 94-102.
- Sherman, D.J. and Hotta, S., 1990. Aeolioan sediment transport: theory and measurements. In Nordsrtom, K.F., Psuty, N.P. and Carter, R.W.G. (eds). Coastal Dunes, Form and Process. John Wiley & Son Ltd.