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Source: Journal of Coastal Research, 85(sp1) : 206-210

Published By: Coastal Education and Research Foundation

URL: https://doi.org/10.2112/SI85-042.1

Journal of Coastal Research	SI	85	206–210	Coconut Creek, Florida	2018

Dynamics of Surface Moisture Content on a Macro-tidal Beach

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ABSTRACT

Montreuil, A-L.; Chen, M.; Brand, E.; Strypsteen, G.; Rauwoens, P.; Vandenbulcke, A.; De Wulf, A.; Dan, S., and Verwaest, T., 2018. Dynamics of surface moisture content on a macro-tidal beach. *In:* Shim, J.-S.; Chun, I., and Lim, H.S. (eds.), *Proceedings from the International Coastal Symposium (ICS) 2018* (Busan, Republic of Korea). *Journal of Coastal Research*, Special Issue No. 85, pp. 206–210. Coconut Creek (Florida), ISSN 0749-0208.

Surface moisture content is a significant factor controlling aeolian sand transport. It is influenced by atmospheric, marine and sub-surface processes. Although several studies reported direct links in surface moisture content with the processes responsible for those variations, there is still a lack of understanding of its dynamic on a macro-tidal beach. This study aims to investigate spatial and temporal dynamics in the surface moisture content of a macro-tidal beach, and to determine the relative importance of factors controlling these. A field experiment was performed on a dissipative and non-barred beach at Mariakerke (Belgium) during an aeolian sand transport event in March 2017. Surface moisture content was measured from the backshore to the tidal zone using a video monitoring system. Simultaneous measurements of grain size, volumetric moisture content, groundwater level, atmospheric conditions, wind parameters, water level and topography were carried out. The hourly generated moisture maps indicate a clear cross-shore gradient of decreasing surface moisture content from the intertidal zone (ranging from 4-18%) to the backshore (none-8%), while it is more complex in the alongshore dimension. The backshore experienced the most rapid reduction of moisture content below 4% with a dryness rate of the surficial zone reaching 29% per hour in the late morning. It progressively continued to dry in the afternoon when sand strips, mobile aeolian bedforms, were well developed. Changes in moisture content over the beach surface reflect the atmospheric (solar radiation and wind) and marine (tidal elevation, wave and groundwater level) conditions and internal beach characteristics such as bedforms produced by aeolian sand transport and topography. Thus the continuous combinations of direct and indirect interactions between all these factors contribute to the spatial and temporal dynamics of surface moisture content. A better knowledge of the dynamics of the surface moisture content is a necessary prerequisite for the development of models and to compute budgets of aeolian sand transport.

ADDITIONAL INDEX WORDS: *Argus video system, aeolian sand transport, sediment size, beach hydrology, Belgian coast.*

INTRODUCTION

Surface moisture content is a significant factor controlling both the threshold of sand movement and aeolian transport rate (*e.g.* Davidson-Arnott *et al*., 2008). Interaction between particles in moist sediment is increased by capillary forces, which result in the existence of water wedges that form at the contact point of the grain, and by adhesion forces determined by the molecular absorption of water onto the surface of the grain (McKenna Neuman and Nickling, 1989). These forces combine to retain water in the sediment matrix increasing the resistance of surface particles to entrainment. Surface moisture content is determined by processes in the atmosphere such as evaporation and precipitation and in the groundwater via capillary transport, which in turn is controlled by the variation of the sea water level. Distribution of the surface moisture on beaches can vary over space and time. It often changes during aeolian sand transport events by either local erosion revealing the underlying wetter sands or local dry sediment accretion on a previous wetted surface (Nield, Wiggs, and Squirrell, 2011). A relatively few field studies have reported surface moisture across the beach, mainly due to the limitation of measurement techniques (surface scrapings, core and probe) and labour time (*e.g.* Atherton, Baird, and Wiggs, 2001). Further, only a few of the available research have attempted to link its variation with the factors responsible for those variations.

Recent advances in remote sensing such as satellite, terrestrial laser scanner, and video system for evaluating surface moisture based on depicted surface brightness apparent allows successfully to acquire instantaneous samples over a large area without disturbing the surface (Delgado-Fernandez, Davidson-Arnott, and Ollerhead, 2012). This technique usually gives a measure of the true surface moisture content (Darke, Davidson-Arnott; and Ollerhead, 2009). In this study, we propose the utilization of an Argus video system to monitor surface moisture content across the beach with a high sample frequency. The aim is to investigate spatial and temporal dynamics in the surface

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DOI: 10.2112/SI85-042.1 received 30 November 2017; accepted in revision 10 February 2018.

*Corresponding author: anne-lise.montreuil@vub.be moisture content of a macro-tidal beach, and to determine the relative importance of factors controlling these.

STUDY SITE

Measurements were conducted on 19th March 2017 at Mariakerke (section 103) located on the west part of the Belgian coast (Figure 1), as a part of a larger study investigating aeolian sand transport. The beach is a flat, dissipative sandy beach exceeded a width of 200 m and linked landward by a dyke. Other human interferences in Mariakerke beach include a groyne field and regular beach nourishments. No vegetation is present on the beach. This coastal section is orientated SW-NE and quite homogeneous in the longshore direction.

The climate is temperate with an annual average temperature of 10.6°C and average rainfall of about 748 mm. Prevailing winds come from SW and are characterized by speeds of 3-8 m/s. The coast is situated in a macro-tidal regime ranging from 3.5 m at neap tide to 5 m at spring tide. The wave climate is from low to medium energy with typical wave heights of 0.5-1 m (Haerens *et al*., 2011).

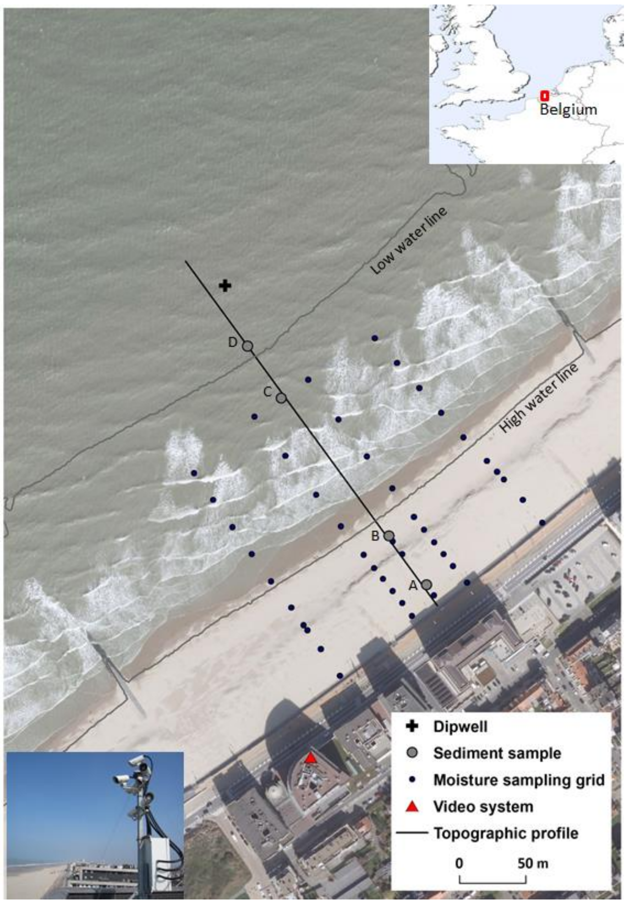

Figure 1. Field deployment and surface moisture sampling grid. Insets: location of the study site and set-up of the Argus video system at the study site.

METHODOLOGY

Image processing, surface moisture content

The Argus monitoring system at Mariakerke is equipped with six cameras looking in different directions and installed on a 44 m high building (Figure 1). It is in operation at the site since June 2014. The Argus system takes hourly snapshot images, which are automatically saved during day light hours and operate through all weather conditions. Camera 2 has a good view on the intertidal zone and the backshore of the site so that it was used to evaluate surface moisture dynamics.

The moisture maps were generated by semi-automatic procedure consisting of moisture calibration, image processing and transformation. In the line with Darke, Davidson-Arnott, Ollerhead (2009), the moisture calibration was carried out by correlating surface brightness measured by the camera with in-situ moisture content measurements from the beach surface. Then digital sampling of pixel brightness was undertaken at beach locations where moisture samples were collected. Pixel brightness values were normalized against the mean brightness value of 3×3pixel values of a white light pole assumed to not change over time. It allows to compensate for the effect of different environmental light in the exposures due to weather conditions and sun angle. A calibration curve was obtained by plotting normalized brightness against percentage moisture content, which makes possible to determine moisture values from pixel brightness values (R^2 of 0.79, calibration curve not presented here). The standard error is in the order of 1.9% moisture, therefore the accuracy of the technique is higher than the Delta-T probe (Atherton, Baird, and Wiggs 2001). A semi-automatic processing of every snapshot images (red-green-blue channels) was applied by converting them to grayscale grids, normalizing the brightness values of the rest of the pixel images, and finally transforming them into moisture content values based on the calibration curve. Moisture maps were thus generated with a cell size of 1×1 m. The error of the moisture maps was of 3%, corresponding to the root-mean square error between the image-processed and the measured surface moisture content. Also, the surface moisture content was monitored with a Delta-T theta probe at different locations across the beach (Figure 1). The probe was calibrated with in-situ sediment samples before the field experiment.

Sediment grain size

Sediment samples were collected by scraping a surface layer approximately 5 mm thick from the sand surface for each station. Sediment size was measured using a laser diffraction particle size analyser in laboratory.

Atmospheric and seawater level conditions

Wind records were collected from the Ostende airport, the closest weather station to the study site. It makes sub-hourly measurements of wind speed and direction. The wind speed and direction have a resolution of 0.1 m/s and 10° respectively. Atmospheric and precipitation data are not available at this weather station so that they were acquired from Zeebrugge weather station located at 25 km from the study site. These were assumed to be representative of the conditions at the study site. In addition, 5-minute water level records were collected from the tide gauge in Ostende harbor.

Groundwater table and topography

A groundwater dipwell was installed along the reference cross-shore profile around the low water to monitor groundwater table elevation (Figure 1). The dipwell consisted of PVC pipe of 2 m in length of 0.05 m of diameter. It was perforated with holes and covered with a fine mesh screen to prevent any entering of sediment. A Cera-diver was installed in the dipwell, measuring the total of the air and water pressure so that an extra sensor was deployed on land to record air pressure. The measurements were taken at 2-minute intervals. The Cera-diver was cabled back to the top of the dipwell casing with a rope which was measured twice before and after the measurement. The locations of the beach surface next to the dipwells were measured with a RTK-GPS device. In addition, beach topography was surveyed with the same device (an accuracy of 2 cm for the x, y, and z coordinates combined).

RESULTS

Atmospheric conditions

Atmospheric conditions were consistent during the study period (Figure 2). Air temperature remained at approximately 10°C and no precipitation was recorded. As expected, the relative humidity was above 80% in the morning and then it dropped to 68% at 13:00 when the solar radiation reached its highest value (639 Watt/m^2). Wind was relatively stable in direction blowing from a highly oblique angle to the coast (240°, alongshore direction) so that fetch distance was unlimited regarding the coastline orientation. Wind speed was above the threshold of sand transport of 7m/s during the entire period (average of 12.3 m/s, standard deviation of 1.6 m/s). A maximum wind speed of 14.6m/s was recorded at 13:20. Aeolian sand transport was observed on the beach during the entire field measurement.

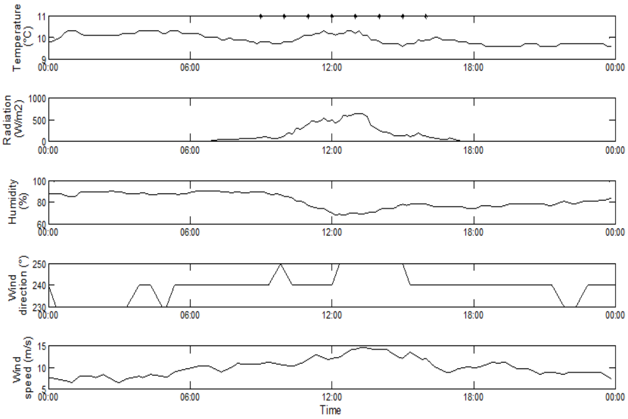

Figure 2. Time series of atmospheric conditions during the study period. Top dots correspond to the time of surface moisture content records.

Sediment characteristics and topography

The particle size data for each station is presented in Figure 3. The sediment consists of fine and medium range, gradually increasing from the backshore (D_{50} of 291 μm at station A) to the lower part of the intertidal zone (D_{50} of 337 μm at station D). Beach profile is characterized by a low slope (2°) with an artificial berm, a remnant from beach nourishments at a distance around 50 m from the dyke, and flat dissipative intertidal area. The distribution of sediment size across the beach thus suggests a spatial variation in wind and marine sorting actions which are also influenced by the topography.

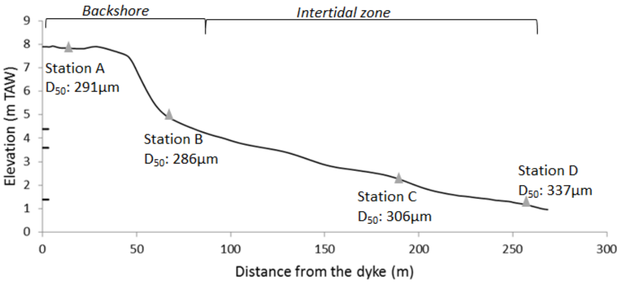

Figure 3. Sediment characteristics across the beach topography. Top, middle and bottom ticks on the y-axis correspond to the spring high water level, the maximum water level reached over the experiment, and the spring low water respectively.

Spatio-temporal trends in surface moisture

Hourly surface moisture maps were produced from camera images taken over the field experiment during a high wind event at neap tide are shown in Figure 4. The maps clearly indicate how surface moisture fluctuates over space and time with corresponding beach topography (Figure 2). The lighter yellow color displays to a low surface moisture content (0-2%), which are visible on the backshore above the maximum water level reached over the experiment (3.6 m TAW). Surface moisture content varies there from none to 8%. While towards the sea, surface moisture content increases, which is displayed with green and grey colours. Surface moisture in the intertidal zone, below the day water line, are generally between 4 and 18%. Between 9:00 and 11:00, the backshore dried out increasingly with moisture values below 4% varying from 28% to 85% of the surficial zone. Thus the increase of dry zone was high with a rate reaching nearly 29% per hour. The intertidal zone, however, remained relatively stable in moisture content. The moisture maps and their respective snapshot images demonstrate the presence of sand strips on the backshore (i.e. light yellow zig zag features observed on the maps). They are transient and mobile dry bedforms commonly observed during high energy sand transport events. A gradual increase in wind speed in the morning (Figure 2) enhanced alongshore sand transport resulting in a drier band around the top of the berm where the sand strips started to develop. Wind speed continuously increased in the early afternoon (>14m/s) and remained relatively strong until the end of the field experiment. Surface moisture maps from 12:00 to 15:00 show that the surficial zone of the backshore progressively became drier below 4% with a rate of the surficial zone of 2%. This was due to a combination of windy and sunnier conditions favouring evaporation across the beach surface, which in turn controlled sand transport. The intertidal zone remained relatively wet with local zones characterized by a moisture content of 16-18% in the afternoon when the observed.

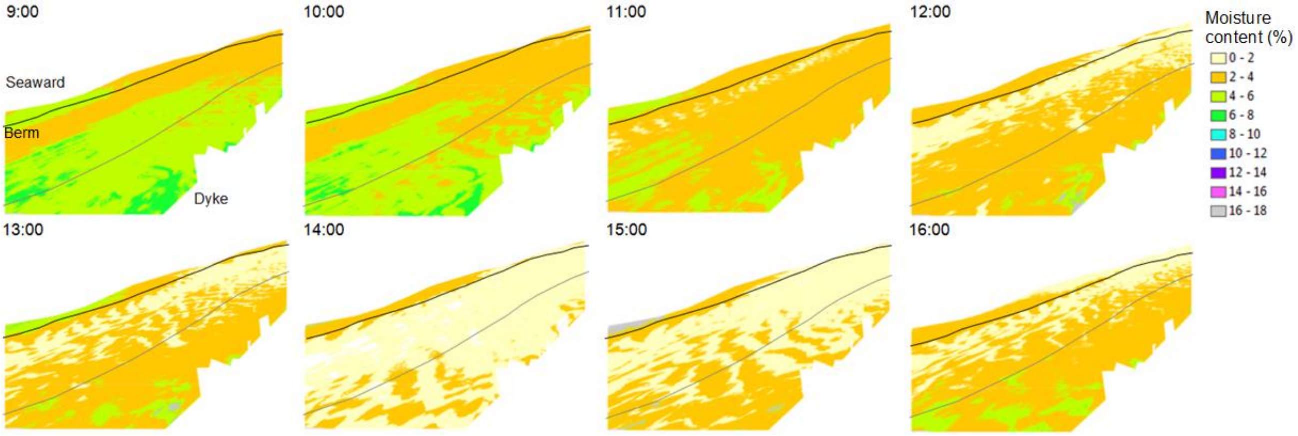

Figure 4. Sequence of surface moisture content maps every hour. The black and grey lines correspond to the maximum water line on 19th March 2017 and the spring high water line.

sand transport was limited. This was caused by the rising of the water level associated with wave run-up from breaking waves By 16:00 the moisture content on the upper beach had again increased reaching value up to 8%. This might be the result of dry sediment erosion leading to an increase of surface moisture due to the exposure of the underlying wetter surface.

Groundwater table and tidal elevation

Groundwater table and tidal elevations recorded during the field experiment taking place at neap tide are presented in Figure 5. The average of the groundwater table position relative to the bed surface was of -0.59 m with a standard deviation of 0.15 m during the study period. In general, it is subject to a cyclic pattern controlled by the water level with a time lag of a couple of hours as previously observed by Nielsen (1990). Tidal elevation fell at 10:00 when a corresponding decrease took place in groundwater table elevation. Thus this latter is subject to a rapid decline associated with the ebb tide. As previously observed, the beach experienced drying between 9:00 and 12:00. This could be due to both gravitational drainage occurring in association with the falling groundwater table and by evaporation process through decrease of relative humidity solar and wind (Figure 2). Although both the tide and groundwater table were rising, the beach continued to dry until 14:00. This suggests that evaporation contributed to drying the beach, while the groundwater table position plays a minor role. By 16:00 the moisture content of the intertidal zone had begun to increase. The rise of the groundwater table was likely sufficient that capillary transport was supplying moisture to the surface sediments and probably enhanced by swash up-rush and wave spray.

Based on Turner and Nielsen (1997), the capillary fringe was calculated. As expected for the sediment sizes, the capillary fringe must in theory be between 22 and 26 cm above the groundwater table. If the latter remains within the threshold from the bed, it could influence on the surface moisture content (Namikas *et al.*, 2010). Thus it is expected that where the groundwater table remains close to the surface little drying of sub-layer sediments will occur. Here, the groundwater table falls below the range of the capillary fringe from the bed for 97% of the time so that its effect is limited on the surface moisture content across the beach.

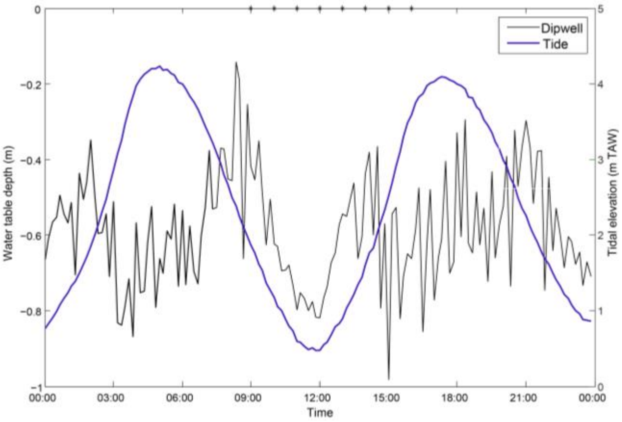

Figure 5. Water table depth and tidal elevation during the study period. Top dots correspond to the time of surface moisture content records.

DISCUSSION

In this study, analysis of moisture maps produced from snapshot images of a video system provides the identification of changes in surface moisture content over a sandy macro-tidal beach. The general pattern evident is the expected cross-shore gradient of decreasing surface moisture content from the intertidal zone to the backshore which is mainly controlled by tidal elevation, and to a lesser extent by internal beach characteristics such as grain size and topography. However, this is more complex in the alongshore dimension. Changes in moisture content over the beach surface reflect the atmospheric (solar radiation and wind) and marine (tidal elevation, wave and groundwater level) conditions and internal beach characteristics related to bedforms produced by aeolian sand transport. Estimates of the surface moisture content above which aeolian sand transport cannot take place vary considerably, but a moisture content greater than 10% is generally agreed to significantly reduce sand flux (Sherman and Lyons, 1994). Although surface moisture directly governs aeolian sand transport, this study suggests that transport observed by the development of the sand strips is in turn an important control on surface moisture content. These bedforms were a source of the sediment in transport. Their dynamic behaviours result from feedback between aeolian sand transport, beach surface properties including moisture content, and bedform migration (Baas, 2007).

The influence of the tide and groundwater table on surface moisture content across the beach is mainly function of time dictated by the magnitude and frequency of the tide level. Therefore, the spatio-temporal dynamics of moisture content across a sandy macro-tidal beach is caused by continuous combinations of direct and indirect interactions between factors. Longer term data of surface moisture dynamics and controlling factors are however needed to fully investigate and quantify the interactions (Delgado-Fernandez, Davidson-Arnott, and Ollerhead, 2009).

The use of video system offers to acquire observations for a large coverage in time and space, no physical disturbance of the sediment surface and its simple approach of generating moisture content maps under any daytime conditions (Darke, Davidson-Arnott, R., and Ollerhead, 2009). Moisture content maps coupled with atmospheric and marine records and monitoring of beach properties provide a great deal of information about the evolving of the beach system and its processes controlling it. Data obtained in this way could be used as one of the inputs in modelling for prediction of aeolian sand transport from the intertidal zone to the backshore over periods of months to years.

CONCLUSIONS

This study examines the beach surface moisture across a sandy macro-tidal beach over a short term field experiment when sand transport occurred. Hourly moisture maps produced from snapshot images of an Argus video system indicate a clear cross-shore gradient of decreasing surface moisture content from the intertidal zone to the backshore, while it is more complex in the alongshore dimension. Changes in moisture content over the beach surface reflect the atmospheric (solar radiation and wind) and marine (tidal elevation, wave and groundwater table) conditions and internal beach characteristics such as bedforms produced by aeolian sand transport and topography. Thus the continuous combinations of direct and indirect interactions between all these factors contribute to the spatial and temporal dynamics of surface moisture content. Moisture maps coupled with atmospheric and marine records, as well as monitoring of beach properties such as grain size, groundwater table, and topography provide a great deal of information and insight about the evolving of the beach system and its processes controlling it. Additional data is needed to fully document and quantify them, which is a necessary prerequisite for the development of models and to compute budgets of aeolian sand transport.

ACKNOWLEDGEMENTS

This research is part of the CREST project, funded by the Strategic Basic Research (SBO) program of Instituut voor Innovatie door Wetenschap en Technologie (IWT).

LITERATURE CITED

Atherton, R.J.; Baird, A.J., and Wiggs, G.F.S., 2001. Inter-tidal dynamics of surface moisture content on a meso-tidal beach. *Journal of Coastal Research*, 17, 482-489.

Baas, A.C.W., 2007. Complex systems in aeolian geomorphology. *Geomorphology,* 91, 311-331.

Darke, I.; Davidson-Arnott; R., and Ollerhead, J., 2009. Measurement of beach surface moisture using surface brightness. *Journal of Coastal Research*, 26, 248-256.

Davidson-Arnott, R.; Yang, Y.; Ollerhead, J.; Hesp, P.A., and Walker, I.J., 2008. The effects of surface moisture on aeolian sediment transport threshold and mass flux on a beach. *Earth Surface Processes and Landforms,* 33, 55-74.

Delgado-Fernandez-Fernandez, I.; Davidson-Arnott, R., and Ollerhead, J. 2009. Application of a Remote Sensing Technique to the Study of Coastal Dunes. *Journal of Coastal Research,* 25, 1160-1167.

Delgado-Fernandez-Fernandez, I.; Davidson-Arnott, R.; Bauer, B.O.; Walker, I.J.; Ollerhead, J., and Rhew, H., 2012. Assessing aeolian beach-surface dynamics using a remote sensing approach, *Earth Surface Processes and Landforms*, 37, 1651-1660.

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.

McKenna-Neuman, C., and Nickling, W.G., 1989. A theoretical and wind tunnel investigation of the effect of capillary water on the entrainment of soil by wind. *Canadian Journal of Soil Science,* 69, 79-96.

Namikas, S.L.; Edwards, B.L.; Bitton, M.C.; Booth, J.L., and Zhu.Y., 2010. Temporal and spatial variability in the surface moisture content of a fine grained beach. *Geomorphology,* 114, 303-310.

Nield, J.M.; Wiggs, G.F.S., and Squirrell, R.S., 2011. 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*, 36, 513-522.

Nielsen, P., 1990. Tidal dynamics of the water table in beaches. *Water Resources Research,* 26, 2127-2134.

Sherman, D.J., and Lyons, W., 1994. Beach state controls on Aeolian sand delivery to coastal dunes. *Physical Geography,* 15, 381-395.

Turner, I.L., and Nielsen, P., 1997. Rapid water table fluctuations within the beach face: Implications for swash zone sediment mobility? *Coastal Engineering,* 32, 45-59.