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Mapping shoreline indicators on a sandy beach with supervised edge detection of soil moisture differences

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ABSTRACT

This study describes a method to map shoreline indicators on a sandy beach. The hypothesis is that, on this beach, spectral albedo is predominantly determined by moisture content and water lines can, therefore, be detected as albedo contrasts. A laboratory experiment is performed to relate moisture content to image albedo, and supervised edge detection is subsequently used to map the shoreline indicators with remote sensing imagery. The algorithm is tested with data from visible, near-infrared and shortwave-infrared wavelength regions. These results are compared to shoreline indicators obtained by a field survey and a shoreline indicator derived from a digital elevation model. Both the water line present when the imagery was acquired, as well as the maximum extent of the last flood, can be detected as a single edge. Older high water lines are confused with the last high water line and appear dispersed, as there are multiple debris lines present on the beach. The low water line, usually in saturated sand, also appears dispersed due to the presence of channels and troughs. Shorelines are constant moving boundaries, which is why shoreline indicators are used as a proxy. Unlike a mathematical indicator that is based on an elevation model, our method is more sensitive to the dynamic nature of shorelines. Supervised edge-detection is a technique for generating reproducible measurements of shoreline indicator positions over time, and aids in the monitoring of coastline migration.

1. Introduction

A shoreline, or coastline, is the physical interface between land and sea (Gens, 2010; Parker, 2002; Short, 1999). Due to the tide and long-term effects such as sea-level changes and sediment transport, the position of shorelines change continuously in time and space (Su and Gibeaut, 2017). Due to this dynamic nature, the “true” shoreline is often represented by a shoreline indicator (Boak and Turner, 2005). The definition of a shoreline thus depends on the selection of the shoreline indicator (Leatherman, 2003). Two types of shoreline indicators can be distinguished: Mathematical and physical indicators. Mathematical indicators are derived from local tide data. Physical indicators consist of morphological and non-morphological indicators. Morphological indicators relate to berm crests, scarp edges, vegetation and dunes. Non-morphological indicators relate to the water line and sand wetness. The high water line (HWL) is well recognisable on a beach and is, therefore, a frequently chosen indicator for remote sensing (Pajak and Leatherman, 2002).

Traditionally, shorelines are drawn with a visual interpretation of terrain features and aerial photographs (Leatherman, 1983). More recently, the mapping of shorelines is aided by high-spatial-resolution optical imagery, RADAR, LIDAR or combinations of topography and bathymetry (Boak and Turner, 2005). Overviews of remote sensing and image processing methods for shoreline detection are in Gens (2010) and Boak and Turner (2005). Most shoreline detection algorithms map the interface between water and land, for example Kelly and Gontza (2018) and de Sousa et al. (2018). The dynamic nature of the coast makes that the measured shoreline locations are subject to wind and tide. Obtaining a cloud-free image product often requires a merge of multiple remote sensing images, leading to an added uncertainty in the position of the coastline (Hagenaars et al., 2018).

This paper describes a novel remote sensing approach for mapping shoreline indicators on the beach. A supervised edge detection technique is applied to optical remote sensing imagery to map several water lines on a sandy beach. This method comes with the hypothesis, tested on sand samples taken from the beach, that differences in spectral albedo are primarily caused by differences in the moisture content of the sand. Along the HWL, three other water lines that are visible in the study area are mapped as well: the previous high water line (PHWL) in the backshore, the instantaneous water line (IWL), and the low water line (LWL) in the tidal plain. These results are compared with the mean high water line (MHWL) that is routinely derived from a digital

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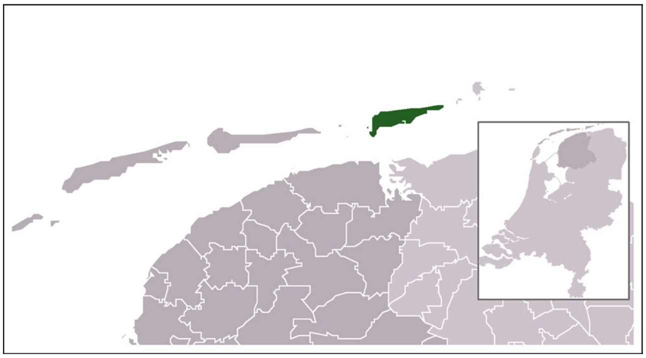

Fig. 1. Location of the island Schiermonnikoog in the north of The Netherlands. The image is copyrighted by the "Statistics Netherlands" (CBS) and is taken without modification from Wikimedia under the CC BY-SA 3.0 license.

elevation model.

2. Study area

Schiermonnikoog is a barrier island located in the north of The Netherlands between the North Sea and the intertidal Wadden Sea (Fig. 1). The 40 km^2-large island is part of a dynamic tidal area and has a mean tidal range of 2.29 m (Hollebrandse, 2005). The northern shore consists of dunes and a broad beach plain; the southern shore consists of salt marshes and tidal flats intersected by numerous creeks and channels. Erosion, transportation and sedimentation of sand by Eastward alongshore currents causes an Eastward migration of the island over time.

The area studied in this paper is on the northern shore (Fig. 2). At this location, the beach slopes 0–2%, is approximately 0.5 km wide when measured from the berm to the low tide water line, and consists of a berm, tidal plain and trough. Behind the beach is a strand-line ridge ("Rijkswaterstaat dune") which was made by planting marrow grass (*Amophila Arenaria*) to protect the sand from wind erosion. Behind the strand-line ridge are dunes. Fig. 3 gives photo impressions of these beach zones.

Fig. 4 shows shoreline indicators present on the beach of Schiermonnikoog. Two of these indicators are related to morphology and vegetation cover: The "dune line", which coincides with the dune scarp, and the "vegetation line", which is the outer limit of the vegetated beach environment. Also, there are four non-morphological indicators: the previous high water line (PHWL) in the backshore, and the high water line (HWL), instantaneous water line (IWL) and low water line (LWL) in the tidal plain. The locations of these four non-morphological indicators depend on sea state and may change within a day. Table 1 lists the physical characteristics of six beach zones that are separated by the shorelines indicators.

3. Method and data

Sand samples were acquired from the beach (Section 3.1) and analysed in a laboratory (Section 3.2) to link the moisture content to spectral albedo. First, mineral composition, organic matter and carbonate content were determined to verify that spectral albedo was not influenced by other materials that could be present in the beach sand. An artificial wetting experiment was done to determine the relationship between spectral albedo and moisture content. Then, a visible (VIS), near-infrared (NIR) and shortwave-infrared (SWIR) band were selected from an airborne hyperspectral image (Section 3.3) and subjected to a supervised edge detection algorithm (Section 3.4) to map differences in spectral albedo as a proxy for waterline indicators.

3.1. Field data

Beach sand samples were acquired on September 27th, 2006, at an incoming low tide, in between high tide at 13:45 Central European Time (CET) (108 cm above Normaal Amsterdams Peil (NAP)) and low tide at 19:55 CET (116 cm below NAP). Both days had a clear sky with no rain, similar to the conditions when the optical imagery was acquired (June 19th, 2005). The samples were acquired in 3 parallel transects that covered the beach profile from the dune crest to the LWL. In each profile, 38 samples were collected. The spacing was 30 m, except for the last 100 m to the LWL, which was sampled at a 4 m spacing as it visually showed irregular patterns in water content. Each sample location was confirmed with a "Garmin E-TREX" handheld GPS that had an estimated positional error of 5 m. The top 4 cm of the sand was taken and stored in plastic hermetic containers to preserve the original amount of moisture as best as possible. Apart from collecting samples, also the current water line was tracked twice with GPS (Section 3.5), and a description of the six beach compartments was made (Table 1).

3.2. Laboratory data

The original moisture content was determined by three times measuring the weight of the samples in a desiccator: Once in their original condition, once after drying in an oven at a temperature of 40 °C, and once after drying at a temperature of 105 °C. The obtained mass differences were recalculated to volumetric water content since photon interaction depends on volume rather than mass (Lobell and Asner, 2002).

An artificial wetting experiment was done to determine the relationship between spectral albedo and moisture content. First, water was added to the oven-dried samples until a thin layer of water was standing on the sample. The thin layer was pipetted off, and the volumetric water content was determined. The samples were subsequently dried in an oven at 40 °C, in seven stages of 1 h each. Every hour, the samples were weighed, and spectral measurements were acquired. An ASD Fieldspec FR Pro was used to collect the spectral measurements. This instrument measures in the 400–2500 nm wavelength range with a 2–3 nm spectral resolution. A high-intensity contact probe with an internal light source was pressed into each sample to ensure identical illumination conditions for all samples. Each sample was measured by averaging five measurements that were taken while moving the contact probe over the sample in between measurements. The relation between volumetric water content and spectral albedo in the VIS, NIR and SWIR wavelength ranges was found by making a linear regression.

The albedo of beach sand is not only depending on moisture content. To determine the presence of other components that could

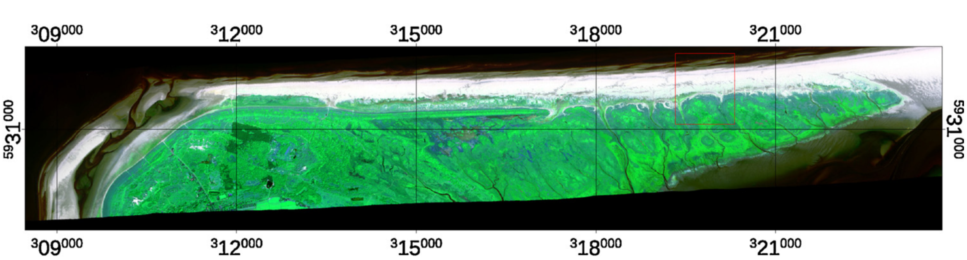

Fig. 2. The red box indicates the 0.99 × 1.31 km study area on the northern shore of Schiermonnikoog. The image is a false colour composite of red: 601 nm; green: 746 nm; blue: 1622 nm. The image has a 3.0 × 3.5 m pixel size and is projected in UTM zone 32N coordinates, shown with a 3-km grid. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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