Coastal Engineering 133 (2018) 113–125

Contents lists available at ScienceDirect

Coastal Engineering

journal homepage: www.elsevier.com/locate/coastaleng

On the accuracy of automated shoreline detection derived from satellite imagery: A case study of the sand motor mega-scale nourishment

Gerben Hagenaars [a,*], Sierd de Vries [b], Arjen P. Luijendijk [a,b], Wiebe P. de Boer [a,b], Ad J.H.M. Reniers [b]

[a] *Deltares, Boussinesqweg 1, 2629 HV Delft, The Netherlands*
[b] *Delft University of Technology, Stevinweg 1, 2628 CN Delft, The Netherlands*

ARTICLE INFO

Keywords:
Automated shoreline detection
Satellite imagery
Google earth engine
NASA
ESA
Positional accuracy
Coastline trends
Coastal management
Dutch coast
Sand motor

ABSTRACT

Measured trends and variability in shoreline position are used by coastal managers, scientists and engineers to understand and monitor coastal systems. This paper presents a new and generic method for automated shoreline detection from the largely unexplored collection of publicly available satellite imagery. The position of the obtained Satellite Derived Shoreline (SDS) is tested for accuracy for 143 images against high resolution in-situ data along a coastal stretch near the Sand Motor, a well-documented mega-scale nourishment along the Dutch coast. In this assessment, we quantify the effects of potential inaccuracy drivers such as the presence of clouds and wave-induced foam. The overall aim of this study is to verify whether the SDS is suitable to study structural coastline trends for coastal engineering practice.

In the ideal case of a cloud free satellite image without the presence of waves, with limited morphological changes between the time of image acquisition and the date of the in-situ measurement, the accuracy of the SDS is with subpixel precision (smaller than 10–30 m, depending on the satellite mission) and depends on intertidal beach slope and image pixel resolution. For the highest resolution images we find an average offset of 1 m between the SDS position and the in-situ shoreline in the considered domain. The accuracy deteriorates in the presence of clouds and/or waves on the image, satellite sensor corrections and georeferencing errors. The case study showed that especially the presence of clouds can lead to a considerable seaward offset of the SDS of multiple pixels (e.g. order 200 m). Wave-induced foam results in seaward offsets in the order of 40 m.

These effects can largely be overcome by creating composite images, which results in a continuous dataset with subpixel precision (10–30 m, depending on the satellite mission). This implies that structural trends can be detected for coastlines that have changed with at least the pixel resolution within the considered timespan.

Given the accuracy of composite images along the Sand Motor in combination with the worldwide availability of public satellite imagery covering the last decades, this technique can potentially be applied at other locations with large (structural) coastline trends.

1. Introduction

The position and evolution of the shoreline along a coastal stretch is important to coastal managers, communities, scientists and engineers. Information obtained from trends and variability in the shoreline position, reveals information on beach variations and is used in coastal zone monitoring, policy making and the design of human interventions. Traditionally, the location of the shoreline is derived from aerial photography or video imagery (such as for instance used in Pianca et al. (2015)) or from in-situ measurements of the beach topography, such as used by Ruggiero et al. (2005), de Schipper et al. (2016) and Turner et al. (2016). According to the two main categories of shoreline definitions by Boak and Turner (2005), the shoreline from aerial photography or video imagery is based on a line that is visible to the human eye and the shoreline from in-situ measurements is based on a common datum or beach volume.

Whereas the collection of traditional shoreline datasets is often expensive and constrained in time and/or space, publicly available satellite imagery provides information on shorelines worldwide for the past 33 years. Potentially this data source is a valuable addition to traditional

---

[*] Corresponding author.
E-mail address: gerben.hagenaars@deltares.nl (G. Hagenaars).

https://doi.org/10.1016/j.coastaleng.2017.12.011
Received 21 June 2017; Received in revised form 7 November 2017; Accepted 16 December 2017

shoreline datasets, especially at locations where limited measurements are available. Until recently, obtaining shorelines from satellite imagery used to be laborious, which limited the use of this dataset to its full spatial and temporal extent. Moreover, a comprehensive study on the accuracy of satellite derived shorelines in relation to obtaining structural coastline trends is not yet available, which hampers the use in practice.

Recently Google launched the Earth Engine platform (GEE) that overcomes the traditional limitations in the usage of satellite imagery. Having both a petabyte satellite image collection and parallel computation facilities combined on the server side of the platform reduces image processing time to only several minutes per image (Gorelick et al., 2017). This increase in processing performance makes it possible to use the full collection of satellite images and allows for the opportunity to perform state-of-the-art image processing techniques such as image compositing (Hansen et al., 2013).

Image processing techniques are available to automatically derive a so called Satellite Derived Shoreline (SDS) position from satellite imagery (García-Rubio et al., 2015). The quality of this position may be prone to disturbances such as cloud cover, foam caused by surf and atmospheric interactions. The positional accuracy of a SDS position may therefore deteriorate by these disturbances, which may hamper retrieving coastline trends. Understanding and quantifying the positional accuracy of SDS positions is essential, and is assessed in for instance Bayram et al. (2008), Kuleli et al. (2011), Pardo-Pascual et al. (2012), García-Rubio et al. (2015), Almonacid-Caballer et al. (2016) and Liu et al. (2017). However, these studies are often limited by the amount of images used, the quality of the in-situ data or the limited range of changes in coastline locations along the coastal stretch. A comprehensive study on the accuracy of SDS positions and coastline trends using a large amount of satellite images is lacking.

To investigate the application range of SDS, we quantify the positional accuracy of an automatically derived SDS for an unprecedented 143 publicly available satellite images. Furthermore, we quantify the offsets in the SDS caused by clouds and waves. We do this by comparing the SDS position to in-situ data for the Sand Motor mega-nourishment. This case study is selected because of its dynamic behavior, which shows significant coastline changes over time and the availability of unique high resolution in-situ measurements to be able to validate the obtained shoreline position and trend.

2. Study site and data availability

The study site is the coastal stretch directly near the Sand Motor nourishment, comprising about 4.5 km of coastline length (Fig. 1). This coastal stretch has an erosive character, which resulted in an extensive nourishment program to maintain a stable coastline. In 2011, a pilot mega-scale nourishment called the Sand Motor was put into place in front of the city of Kijkduin, which provides the adjacent coast with sediments for the coming 20 years (Stive et al., 2013).

An average tidal range of 1.7 m and a mean significant wave height of 1.3 m (Wijnberg, 2002) are observed along the Sand Motor. After 18 months, a landward shift of 150 m was observed near the tip of the sand motor, accompanied with an alongshore spreading of about 4 km (de Schipper et al., 2016). Focusing of wave energy is observed near the tip of the peninsula, leading to a local steepening of the beach profile. After the first storm season, a tidal lagoon developed with a tidal channel extending in the northern direction that shifts course over time.

High resolution and frequently measured in-situ data on the dynamic development of the topography and hydrodynamics is amply available for the Sand Motor. Validating the position along such a dynamic study site against high resolution in-situ data provides new insight into the applicability of the SDS detection method to study equally or less dynamic coastal areas. The Sand Motor case is studied for the period 2011-08-01 (just after completion of the nourishment) to 2016-07-01.

The SDS position is compared to concurrent in-situ measurements of the shoreline, obtained from topographic surveys and water level measurements. The topographic survey of the Sand Motor has been conducted on a monthly basis for the first year after completion and on a bimonthly basis until present, resulting in a total of 36 topographic surveys. The topography of the Sand Motor study site is measured along transects spaced alongshore by 30–60 m (de Schipper et al., 2016). All available Landsat 5 (Thematic Mapper, TM), Landsat 8 (Operational Land Imager, OLI), Landsat 7 (Enhanced Thematic Mapper, ETM+) and Sentinel 2 images for the Sand Motor study site are listed in Table 1. The Landsat 7 Scan Line Corrector (SLC) failed in May 2003, resulting in large data distortions of the image (Wijedasa et al., 2012). Since the analysis period is after the SLC failure, the Landsat 7 images are left out of the analysis.

Water level measurements that include both tide and surges are obtained from the measurement stations at Hoek van Holland and the port of Scheveningen. These stations are located adjacent to the coast by about 10 km south and 7 km north with respect to the tip of the peninsula. Offshore wave data (wave height, period and direction) are obtained from the IJmuiden (located 56 km offshore) and Europlatform (located 62 km offshore) measurement stations. A nearshore significant wave height is found using a Simulating WAves Nearshore (SWAN) model (Booij et al., 1999), which transforms wave characteristics from

Table 1
Overview of the amount of satellite images per satellite mission available for the Sand Motor study area in the period of 2011-08-01 to 2016-07-01.

Satellite mission	Sensor	Number of images	Pixel resolution [m]	Temporal extent
Sentinel 2 (A)		40	10 × 10	>2015-07
Landsat 8	OLI	99	30 × 30	>2013-04
Landsat 7	ETM+	112	30 × 30	>2011-08
Landsat 5	TM	4	30 × 30	1984-01 - 2011-10

Fig. 1. Overview of the Dutch Delfland coastal cell bordered by Hoek van Holland (left) and Scheveningen (right). The Sand Motor study site is indicated in red. Depths at the −8 m, −5 m and +2 m NAP iso-contours are indicated in grey. The underlying satellite image (SPOT mission) was acquired on 18-05-2014. The water level measurement stations of Hoek van Holland and Scheveningen are indicated by means of a red dot. A nearshore location at the −10 m NAP depth contour, on which nearshore wave data are available, is indicated in yellow. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)