Measured gradientsin alongshore sediment transport along the Dutch coast

De Vries, S.; De Schipper, M. A.; Stive, M. J F

Publication date
2014

Document Version
Final published version

Published in
Proceedings of the 34th International Conference on Coastal Engineering, ICCE 2014

MEASURED GRADIENTS IN ALONGSHORE SEDIMENT TRANSPORT ALONG THE DUTCH COAST

S. de Vries[1], M.A. de Schipper[1], M. J.F. Stive[1]

In this paper it is aimed to quantify bulk (surf-zone integrated) alongshore sediment transport using morphological data collected along the Dutch coast. The collected morphological data covers a domain of 18 km alongshore including the beach, the foreshore and the intertidal zone in the cross shore. The measurement domain contains the 20 million m^3 Sand Engine mega-nourishment. Detailed volume changes in cross shore profiles are calculated using the collected data. Based on the calculated volume changes in the cross shore profiles, gradients in alongshore transport can be derived. In the scope of this paper we have derived alongshore transport gradients considering three periods; 1) a period of one year; 2) a period of two months with mild wave conditions; 3) a period of four months with stormy weather. Changes in the derived gradients in sediment transport for the selected periods are significant depending on alongshore location and temporally varying forcing conditions. The potential of the data-set is only explored to a limited extent so far. Additional parameters to be analyzed in the future are coastline orientation and cross shore profile gradients.

Keywords: Alongshore sediment transport; Sand Engine; Topographic measurements

INTRODUCTION

In this paper it is aimed to quantify bulk (surf-zone integrated) alongshore sediment transport using morphological data collected along the Dutch coast. According to traditional concepts, alongshore sediment transport (S) is related to the alongshore component of the wave energy flux.

$$S \propto (Ec_g)_b \cos\phi_b \sin\phi_b \tag{1}$$

where ϕ indicates the coastline orientation (shore normal) with respect to the wave direction, E is the wave energy, c_g represents the wave group velocity (or the velocity of the energy propagation) and subscript b indicates values at breakpoint of the waves. Commonly used bulk formulations for calculating alongshore sediment transport (S), such as the CERC (1984) and Kamphuis (1991) formulations, are based on this concept.

It is therefore expected that if at a certain location the coastline orientation varies, the alongshore sediment transport varies accordingly. Where the alongshore sediment transport increases or decreases in alongshore direction, erosion or sedimentation takes place respectively. The volume of the erosion/sedimentation (ΔV) can be estimated using an interpretation of the Exner equation (in this case excluding effects due to porosity):

$$\frac{\partial S(x,t)}{\partial x} = -\frac{\partial V(x,t)}{\partial t} \tag{2}$$

where x is the alongshore distance. State of the art coastline models often use similar conceptual theory (elaborated in more detail) combined with some assumptions on coastline behavior as a basis. Examples include UNIBEST, LITPACK and GENESIS which are commonly used in engineering practice.

Despite this common applied use, there is still some debate on how to calculate alongshore sediment transport (Mil-Homens et al., 2013). There is generally a large spread in outcomes of different formulas, and a large scatter in the model data comparisons. This might partly be caused by the fact that it is very difficult to measure actual rates of alongshore sediment transport in the field

In this paper we aim to estimate rates of alongshore sediment transport using very detailed topographic measurements of a particular field case combined with an assumption of continuity (Equation (2)). The data-set has been collected to be able to analyse relatively large and small scale coastal processes and the data-set has therefore some unique properties.

THE FIELD SITE & DATA-SET

The domain is located at the southwest end of the Holland coast (see the left panel of Figure 1). The coast is characterized by a 18 km long sandy beach and is bordered at the north and south side by harbor moles. The domain includes the mega nourishment project of the Sand Engine described in Stive et al. (2013).

The Sand Engine is a, one of a kind, mega nourishment of 20 million m^3 of sand. The sand nourishment is shaped like a shore connected hook and is designed to erode over time feeding the full alongshore extent of the 18 km of coast. The estimated timescale of this feeder nourishment is 10-20 years.

[1] Department of Hydraulic Engineering, Delft University of Technology, The Netherlands

The dataset covers the full alongshore extent of 18 km. Topographic transects are measured every 20-40 m from the dune foot down to a depth of 6 m. A total of 630 transects have been measured on a regular basis. It is aimed to gather a new topographic dataset at intervals of two months between early 2013 until 2016. Table 1 gives an indication on the surveys which have been executed at the time of writing. Data is collected using RTK GPS techniques combined with single beam echo sounder on a Jetski and RTK GPS on a Quad bike. In the left panel of Figure 1, an overview of the survey domain and a selection of the survey transects is shown. The positive alongshore axis (x) is defined in km from north to south to comply with local conventions.

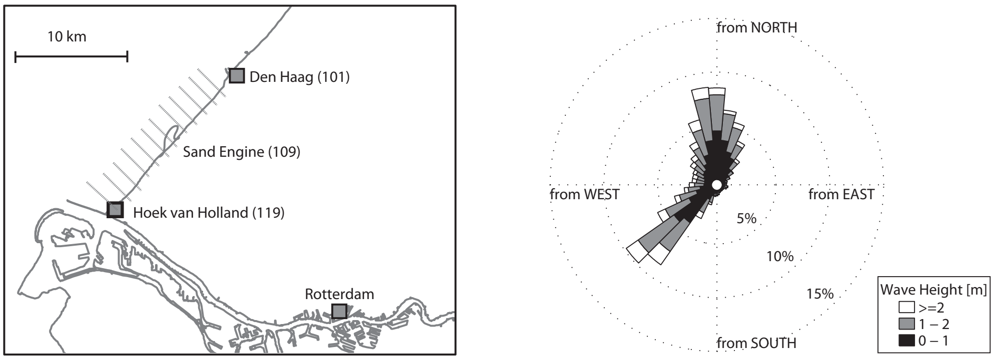

Figure 1: The left panel shows an overview of the domain including a selection of the (630) transect locations. The Sand Engine is visible in the middle of the domain. The right panel shows the typical annual wave conditions (derived from measurements at Europlatform located about 60 km offshore for the years 2012 and 2013).

The average wave height at the measurement location is around 1-1.5 m and the vertical tide range is between 1.5-2 m. Wave directions are distributed bi-modally (see the right panel of Figure 1). The modal directions, south-west and north, have a large alongshore component generating significant alongshore transport. Rates of gross alongshore transport in this area have been estimated in the past to be around 500.000-600.000 m^3/yr northward and 400.000 m^3/yr southward. The resultant sediment transport is northward and is estimated between 100.000-175.000 m^3/yr. Details on these estimations of alongshore sediment transport can be found in Stive and Eysink (1989) and van Rijn (1997). The cross shore transport over the -20 m depth contour (between the offshore zone and the coastal zone) is estimated by van Rijn (1997) around 150.000 m^3/yr in landward direction. To the authors knowledge, no estimates exists to what extent there is significant sediment input from the rivers Rhine and Meuse discharging through the harbor channel.

METHODOLOGY

Figure 2 shows 2 profiles measured at one transect location near Hoek van Holland with about a one year interval. At this particular transect location, significant accretion (positive volume change ΔV) is measured. The volume change is derived for all 630 individual transect locations. As a result an alongshore distribution of volume changes is derived indicating locations of erosion and accretion, see the left panel of Figure 3 for an example.

The derived volume changes can be used to estimate net sediment transports aggregated over time

Surveynumber	Surveydate
1	Feb/Mar 2012
2	Feb/Mar 2013
3	Apr/May 2013
4	Jun/Jul 2013
5	Aug/Sep 2013
-	~~Okt/Nov 2013~~
6	Dec/Jan 2013
7	Feb/Mar 2014
8	Apr/May 2014

Table 1: Overview of measurement dates. Due to bad environmental conditions there is no survey in Okt/Nov 2013. The gray cells indicate the particular surveys which are used in this paper.

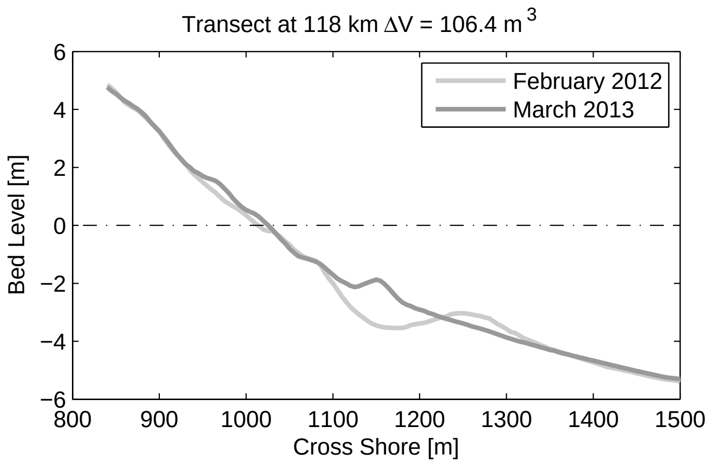

Figure 2: Example of measured profiles of the first two surveys. Transect location is located close to Hoek van Holland. The horizontal line indicates the mean sea level.

$(S(x, t))$ intergrating Equation (2) in alongshore direction:

$$S(x, t) = -\int \frac{\Delta V(x, t)}{\Delta t} dx \tag{3}$$

where Δt is the time between surveys and x (and dx) the distance alongshore. We integrate in x direction from $x = 101$ km to $x = 119$ km. At the harbor mole at the most southern side we assume for the moment that no sediment enters or leaves the domain passing this harbor mole. To calculate the alongshore distribution of aggregated sediment transport, zero transport is therefore assumed at the southern boundary of the domain ($S(119, t) = 0$). An example of the results are shown in the right panel of Figure 3.

RESULTS

Using the described methodology we are able to produce estimates of alongshore sediment transport related to any pair of topographic measurements given in Table 1. Within the scope of this paper we have selected three periods; 1) The first year of development; 2) a 2 month period with relatively mild wave forcing; 3) a 4 month stormy period.

First year development

From the derived volume changes (left panel of Figure 3) it is clearly visible that at the Sand Engine, erosion volumes are relatively large (O (500 m^3/m)). Just adjacent to the Sand Engine, deposition is measured at the north and the south side of similar order. Moving further away from the Sand Engine in alongshore direction, volume changes are typically smaller.

The right panel of Figure 3 shows alongshore transport derived using Equation (3). It is shown that derived alongshore sediment transports are both positive and negative. The sign of the derived sediment transport intuitively indicates the spatial direction of the transport but it should be noted that the sign is at least partly determined by the chosen boundary condition at the southern end of the domain ($S(119, t) = 0$).

Gradients in sediment transport are particularly large around the Sand Engine area. The large positive (erosive) gradient in transport is around 60.000 m^3 over 2 km. The negative (accretive) gradients on either side of the Sand Engine are around 20.000 m^3 over 1 km at the south side and 40.000 m^3 over 1 km at the north side. The total signature of the Sand Engine in the considered domain and data involves an alongshore distance of 4 km.

A change in the total sediment volume in the measured domain is indicated by the nonzero value at the northern end of the measurement domain. This change suggests an increase of the total sediment volume of 18.000 m^3. This change in total sediment volume could be governed by sediment input from the north and south side of the measurement domain as well as the exchange with the offshore area outside the measurement domain.

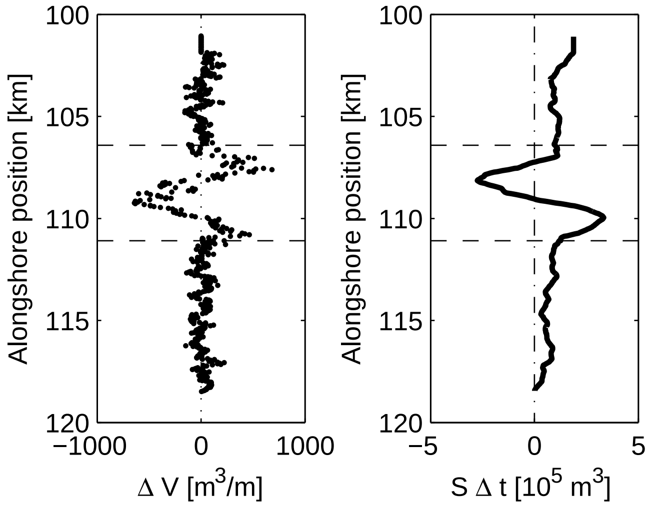

Figure 3: The left panel shows the measured volume change between the first two surveys (Table 1). The right panel shows the derived net sediment transport using Equation 3. Note that these transport are related to the period between measurements. The horizontal dashed lines indicate the area of the Sand Engine.

Quiet months

Figure 4 shows the results from the derived volume changes and the corresponding derived gradients in alongshore sediment transport during a period with mild wave forcing of 2 months. The quiet period is characterized by small waves. While wave power was small during these months, tidal currents are relatively large with respect to wave induced processes.

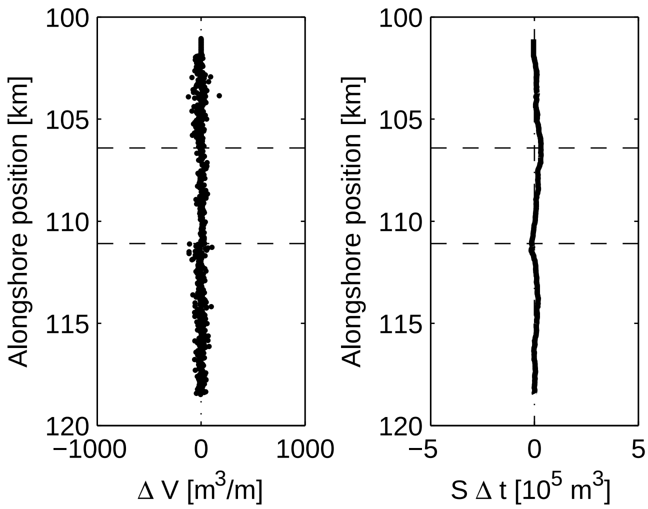

Figure 4: The left panel shows the measured volume changes during a relatively quiet period (July 2013-August 2013). The right panel shows the derived net sediment transport using Equation 3. Note that these transport are related to the period between measurements. The horizontal dashed lines indicate the area of the Sand Engine.

Measured volume changes in all profiles are small (< 100 m^3) and corresponding derived gradients in sediment transport are very small. This result highlights a dominant role of wave processes for alongshore sediment transport gradients at the considered zone. Moreover, no signature of transport gradients near the harbor moles at the northern and southern boundaries are visible.

Stormy months

Figure 5 shows the results from the derived volume changes and the corresponding derived gradients in alongshore sediment transport during a stormy period. Winds were relatively strong and wave heights were relatively high during this period.

Between km 114-117 a nourishment is implemented during this period. This nourishment has likely led to the measured volume change of 13.000 m^3 over 3 km in this area. Moreover, the derived negative gradient between km 114-117 can probably be attributed to this artificial sand nourishment at this location.

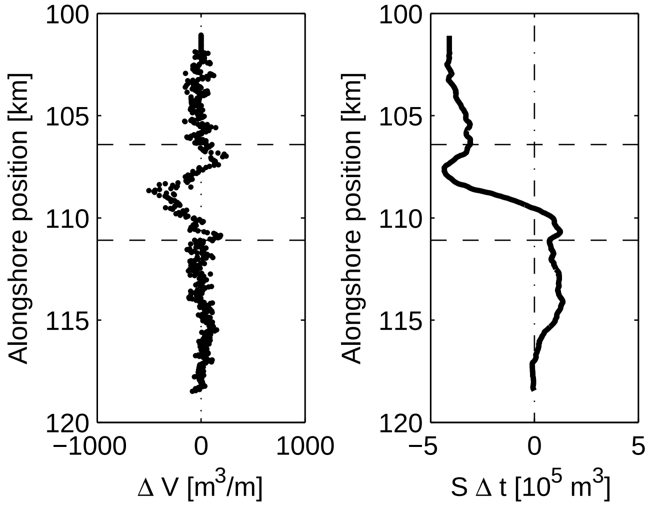

Figure 5: The left panel shows the measured volume changes during a stormy period (December 2013-Februari 2014). The right panel shows the derived net sediment transport using Equation 3. Note that these transport are related to the period between measurements. The horizontal dashed lines indicate the area of the Sand Engine.

Magnitudes of volume changes in this relatively short period are comparable with the volume changes during the full year period shown above. The pattern of derived gradients in alongshore transport are somewhat different with respect to the full year period shown above.

A significant positive gradient in alongshore transport over the entire domain is derived. The total erosion in the measurement domain during this period is around 40.000 m^3. This gradient seems to be largely governed by erosion volumes measured in the Sand Engine area. The derived positive gradient in the Sand Engine area is around 55.000 m^3 over 3 km. Just adjacent to the Sand Engine, a limited negative (accretive) gradient of 13.000 m^3 over 1km exists on the north side. No significant negative gradient exists just adjacent on the south side of the Sand Engine.

Moving further north with respect to the Sand Engine, a positive gradient in derived alongshore transport of around 10.000 m^3 over 3 km exists. This positive gradient could possibly be explained by negative volume changes while sediment moves offshore outside the measurement domain.

DISCUSSION AND OUTLOOK

In this paper we have shown early results of derived gradients in alongshore sediment transport. Moreover, we have analyzed part of the total amount of available data to a limited extent. Early results of the analysis look promising and there are some early lessons learned, some anticipated future work but also some drawbacks of the data-set to be reported.

- Derived gradients in alongshore sediment transport show significant differences depending on the alongshore location and the temporally varying forcing conditions. During mild wave forcing gradients are of smaller order than during stormy periods.

- The current measurements go to a water depth of 5-6 meters only. This particular depth was the result of budget limitations and the choice for a large alongshore resolution rather than cross shore extent. Morphological changes extent further in cross shore direction that the 5-6 m depth contour. This is a problem when analyzing sediment budgets. Morphological data which is collected yearly at the Dutch coast within the JARKUS program (see Southgate (2011) for a thorough description of this data set) could possibly be used in addition to overcome this problem.

- In this paper we consider the volume changes using the measured transects. However, the measured transects contain many parameters which are not yet explored. Examples are coastal orientation, foreshore slope, beach width, bar system and depth of closure. A next step in the analysis is to include coastal orientation with respect to the wave directions. This step is expected to make a link between the derived alongshore sediment transport and traditional formulations for alongshore sediment transport. Moreover, taking coastal orientation with respect to the wave into account might provide useful information for models describing high angle of wave instabilities described by amongst others van den Berg et al. (2014).

ACKNOWLEDGEMENTS

This work is funded under the ERC advanced Grant 291206-NEMO.

References

CERC, 1984. Shore protection manual. Tech. rep., Coastal Engineering Research Centre, Army Engineer Waterways Experiment Station, Vicksburg.

Kamphuis, J., 1991. Alongshore sediment transport rate. Journal of Waterway, Port, Coastal, and Ocean Engineering 117 (6), 624–640.

Mil-Homens, J., Ranasinghe, R., van Thiel de Vries, J., Stive, M., 2013. Re-evaluation and improvement of three commonly used bulk longshore sediment transport formulas. Coastal Engineering 75 (0), 29 – 39.

Southgate, H. N., 2011. Data-based yearly forecasting of beach volumes along the dutch north sea coast. Coastal Engineering 58 (8), 749 – 760.

Stive, M., Eysink, W., 1989. (in dutch) voorspelling ontwikkeling kustlijn 1990-2090, fase 3 (deelrapport 3.1) : dynamisch model van het nederlandse kustsysteem, rapport h0825. Tech. rep., WL/Delft Hydraulics.

Stive, M. J., de Schipper, M. A., Luijendijk, A. P., Aarninkhof, S. G., van Gelder-Maas, C., van Thiel de Vries, J. S., de Vries, S., Henriquez, M., Marx, S., Ranasinghe, R., Aug. 2013. A new alternative to saving our beaches from sea-level rise: The sand engine. Journal of Coastal Research, 1001–1008.

van den Berg, N., Falqués, A., Ribas, F., Caballeria, M., 2014. On the mechanism of wavelength selection of self-organized shoreline sand waves. Journal of Geophysical Research: Earth Surface 119 (3), 665–681.

van Rijn, L. C., 1997. Sediment transport and budget of the central coastal zone of holland. Coastal Engineering 32 (1), 61–90.