Methods for analysing morphodynamics of tidal inlets

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ABSTRACT

A major part of the world's coast consists of sequences of barrier islands and tidal inlets. Tidal inlets are highly dynamical systems, influencing the surrounding environment as well. The inlets contain morphological units: tidal channels, sandbanks, etc. A method is developed regarding the analysis of morphological units in space and time, including quantitative volumetric analysis. The method is applied to the Ameland inlet, a study site situated in the Dutch Wadden Sea. The dynamics of tidal inlets: e.g. deformation, displacement, whether a channel is filling up, etc. can be analyzed objectively using the developed method.

Keywords

Data analysis; Morphodynamics; Tidal inlet; Wadden Sea; Tidal channels; ArcGIS.

INTRODUCTION

Tides dominate salt water bodies all over the world. A major part of the world's coast is formed by sequences of barrier islands and inlets, which are influenced by tides (Elias et al. 2006a). In general, a tidal inlet is a gap in the coastline exposed to the interaction of tidal currents and wind waves (Hayes 1980), which enables exchange of water, sediments, nutrients, etc. between the open sea and the back-barrier basin (Elias et al. 2006b). Tidal inlets consist of a main tidal channel with on both sides' marginal channels, interacting with different sandbars/shoals. Flood tidal currents mainly flow through the main channel, while ebb tidal currents flow through the marginal ebb channels (Hayes 1980). This highly dynamical system is well-studied since decades (e.g. Hayes 1980; Aubrey et al. 1984; Elias et al. 2012b), due to its practical regarding sea level rise (e.g. Van der Spek et al. 1992), due to the surrounding inhabited coast/barrier islands and also the influence of human interventions on valuable nature and ecosystems (e.g. Beets et al. 1994; Oost et al. 2001). Data analyses done so far are unraveling the dynamics of large scale morphology using sediment budgets, i.e. changes in bathymetry over time, and conceptual theories qualitatively describing the dynamics of channels and shoals (e.g. Elias et al. 2006b; Elias et al. 2012b). However, more knowledge has to be developed to understand the various smaller scale morphological units, in particular to understand their size, shape and behavior (Wang et al. 2012). Quantitative studies of these morphological units (channels, sandbars, shoals, etc.) are lacking. Analyzing the movements of these 3D volumes in space and time can contribute to understand the developments of the bathymetry of tidal inlets and the surrounding environment. We aim to acquire more insight in the dynamics of tidal inlets by quantitatively studying morphological units. This leads to the following research question: what method can be developed to objectively track 3D volumes (morphological units) through space and time and to determine the development of these 3D volumes quantitatively? First the study area where the method is applied will be highlighted. Then this paper describes the developed method using the software ArcGIS. The results regarding the developed method using the study area will be explained and the paper will be finalized with a discussion of the method and conclusions regarding the development of the study area as well.

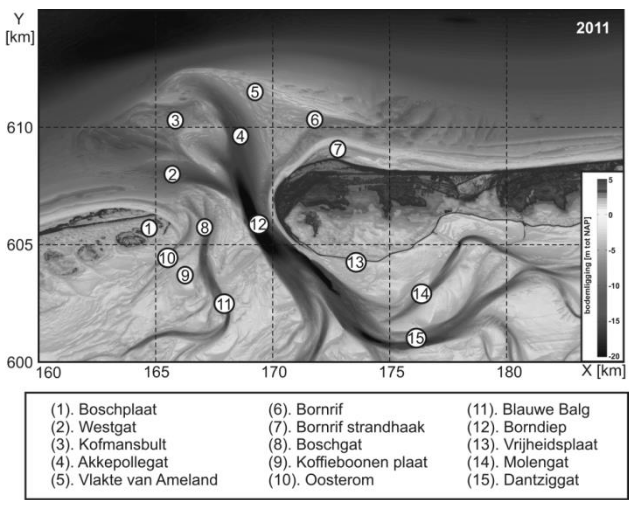

Figure 1: Morphological state of the Ameland inlet in 2011 (Elias et al. 2013)

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STUDY AREA

The Dutch Wadden Sea with the associated barrier islands originated 7000 years ago (Beets et al. 1994). The Ameland inlet, located between the barrier islands Ameland and Terschelling (Fig. 1), consists of several dynamic morphological units. Israël (1998) analyzed historical bathymetric data and described the morphological dynamics of the tidal inlet as a cyclic development of 50 to 60 years. This cyclic development shows transitions between a one- and two-channel system. A continuation of this cyclic behavior is not yet shown (Elias et al. 2012a). The developed method for data analysis is applied to the large scale well-analyzed Ameland inlet, to study the historical, current and future development of the morphological units and the related cyclic development. Developed theories for this inlet can attribute to the validation of this method and the method can vice versa attribute to the fundamentals of the theories. In addition, this study area is used to prove the practical applicability of the method on different morphological units, before the method can be applied to tidal inlets worldwide.

METHODS

Bathymetric data from the study area, made available by The Dutch Ministry of Infrastructure and the Environment, forms the basis for this study. The dataset is composed using measurements collected with single-beam echo sounders combined with near-shore coastline measurements. The resulting data is digitally stored in ‘Vaklodingen’, an interpolated grid of 20 x 20m (De Kruif 2001; Elias et al. 2012b). The dataset only provides the entire bathymetry of the Ameland inlet in: 1971, 1975, 1981, 1989, 1999 and 2011. Also the incomplete measurement of 2004 is used for the analysis. The data, stored as raster data, is processed in ArcGIS. A Geographic Information System (GIS) is used to visualize, interpret and analyze (spatial) data. To analyze whether the volume of a certain morphological unit is increasing or decreasing on the outer and/or inner delta, the bathymetry is split by a boundary between both barrier islands, resulting in a separate analysis for the inner- and outer delta of the tidal inlet. The shortest line between the adjacent islands is determined using the ‘basiskustlijn’ (basic coastline; BKL), which is the coastline captured in 1990 and used as reference from that time. The BKL is subjected to well-reasoned revisions (Ministerie van Infrastructuur en Milieu 2012), the initial BKL is used for the entire analysis, resulting in a robust boundary that is insensitive to external changes. For an objective non-arbitrary analysis, a contour line at a specific height is chosen for enclosing a 3D volume. This contour line can be chosen at specific heights, for this study site e.g. at -10m +NAP (representative for the main channel), -2m +NAP (just below low water) and +2m +NAP (high water). By analyzing a morphological unit at multiple depths/heights during a certain period, the development of the vertical shape can be described. By analyzing a morphological unit at the same depth/height during a certain period, the shift of the displacement can be showed. The development of the entity surrounded by the contour line can be analyzed quantitatively by calculating the volume of water present in the surrounded area below the representative height of the contour line. The following equation is used:

$$V = \sum_{i=1}^{k} a_i * h \qquad \textbf{Equation 1}$$

Where V is the volume of the water in/above the morphological unit, under the specific height of the contour line. i is a grid cell and k is the total amount of grid cells. a_i is the surface area of the grid cell and h is the vertical distance between the bed level at the grid cell and the height of the specific contour line. The method is applied to the Akkepollegat combined with the Borndiep

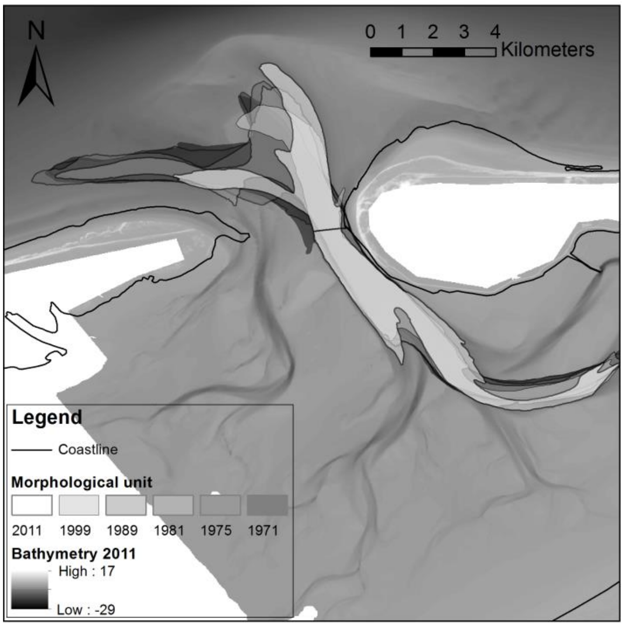

Figure 2: Dynamics of the Akkepollegat and Borndiep at -8 m +NAP

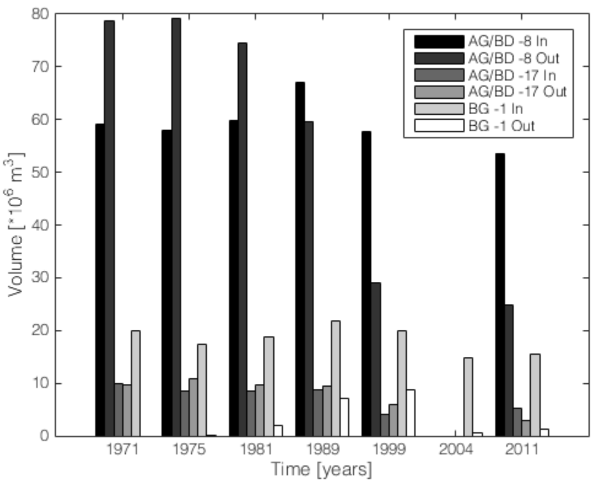

Figure 3: Volume of the channel (the numbers show the height of the contour line [m +NAP], ‘In’ means inner delta, ‘Out’ means outer delta, ‘AG/BD’ means Akkepollegat combined with Borndiep and ‘BG’ means Boschgat)

(Fig. 1), which are analyzed for the contour lines at -8 meter +NAP and -17 meter +NAP. The Boschgat (Fig. 1) is studied using the contour line at -3 meter +NAP.

RESULTS

The developed method shows an overview of the dynamics of the analyzed channels that are part of the historically based cyclic development of the tidal inlet (Israël 1998). The Akkepollegat and the Borndiep are analyzed at the contour line -8 meter +NAP (Fig. 2). Combined with the volume of the channel at the specific years (Fig. 3), at the contour lines -8 and -17 meter +NAP, it can be stated that the volume of the channel (below -8 m +NAP) remains equal at the inner delta of the inlet and decreases at the outer delta of the inlet. The volume of the deepest part of the channel (below -17 m +NAP) is decreasing, so the channel is filling up. However the equal remaining inner delta (below -8 m +NAP), shows that the channel is widening at that location. The Boschgat (Fig. 4) can be analyzed only at the inner delta of the inlet due to the lack of suitable contour lines at the outer delta. The volume of this channel is randomly changing, however the channel shows a trend in the displacement. The mouth of the channel is shifting from a North-Eastward orientation at the inner delta to a Northward orientation at the outer delta and back to a Northward orientation at the inner delta. The method applied to the study area gives the indication that the cyclic behavior as described by Israël (1998) is not yet continuing. However, the direction in which the two channels are migrating might indicate that the system will change into a one-channel inlet. This is an indication of the continuation of the cyclic behavior, in contradiction to the randomly changing volume of the Boschgat (Fig. 3).

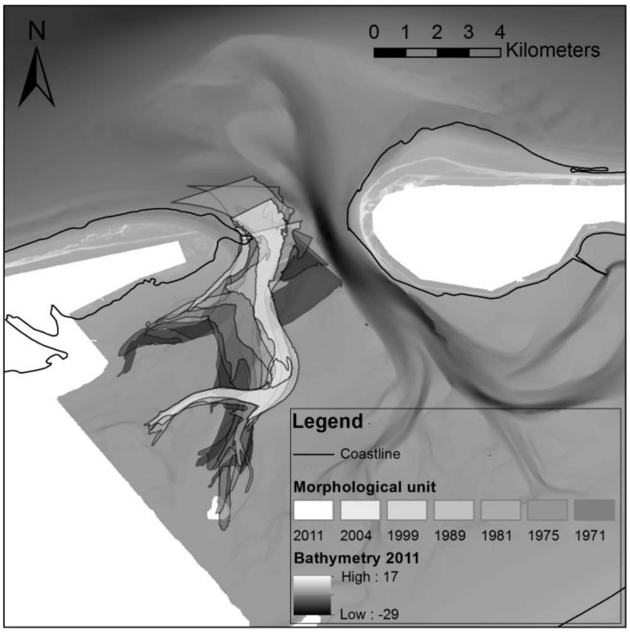

Figure 4: Dynamics of the Boschgat at -3 m+NAP

DISCUSSION

A method is developed regarding the analysis of 3D volumes in space and time, including quantitative volumetric measurements. The method is able to analyze specific morphological units, and depends on the presence of a closed contour line throughout the entire time series. Figure 4 shows that the outer delta of the Boschgat cannot be analyzed due to the decreasing bottom level. In that case the boundary between the inner and outer delta must be used, a partly arbitrary selection should be made or a deeper contour should be chosen, which results in a smaller selection. The shallow parts of a pronounced channel cannot be analyzed due to the increasing surface of the selection, which results in inclusion of areas that are not part of the morphological entity. The BKL is used to define the coastline in this study. The method does not show major differences when using another definition for the coastal boundary. Major changes are mainly found at the branches of the channels and not between the islands. During this study other methods are taken into account and/or are developed as well. Sedimentation-erosion maps (bathymetry year x minus bathymetry year $x-1$) are analysed by creating polygons automatically using ArcGIS. This is a promising method, due to the entirely automatic process. However, due to the basis of two combined years (sedimentation-erosion), the difference is analyzed only, pronounced polygons present over the whole period cannot be found.

CONCLUSION

This study shows that the developed method gives a clear objective, non-arbitrary view of the specific channels present in the Ameland inlet in space and time. The method includes quantitative data for the dynamics of morphological units for a specific year as well. The developed method should be applied to other tidal inlets around the world, this will test the method on the one hand and will show a clear analysis of the different morphological units at the specific tidal inlet on the other. Finally, different selections can be made using the developed method, e.g. for calculating the total volume of all channels, sandbanks, etc. in the entire inlet, which gives insights whether the inlet is filling up or increasing. This study can add a small piece of knowledge regarding the extremely dynamic tidal inlets all over the world.

ROLE OF THE STUDENT

This individual study is conducted within the company Deltares and is supervised by a University of Twente supervisor and staff from Deltares. The entire paper is written by the first author (the student). The second and third author of the paper both were supervisors during the study. They gave constructive comments when writing the paper as well, that feedback is processed by the first author. The methods (developed during this study) currently are used for analyzing morphological units.

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