Ripple filtering and ridge enhancement applied to morphodynamical tracking of sand dunes.

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ABSTRACT: A 3D global semi-automatic approach based on bathymetric triangulated irregular network (TIN) is developed to extract the overall sand dunes pattern inside a given area. This method takes advantage of a new purpose-built anisotropic filter able to enhance the dominant features of the bathymetric mesh surfaces while smoothing out their ripples. The salient ridge and valley lines of the sand dunes are automatically extracted as 3D parametric curves trough a saliency indicator. This new approach is tested on a fourteen years long time series of thirty MBES bathymetric datasets acquired by the Continental Shelf Service of the FPS Economy of Belgium on a monitoring area located on the northern part of the Middelkerke bank (Flemish banks, Belgian part of the North Sea). Based on the 3D vectors resulting from this approach, 3D augmented representation can right now assist geoscientists in tracking dunes morphology and dynamic but calculation methods should be specifically developed to assess the magnitude and direction of the dunes movement and evaluate the volume of sand involved in the dune dynamics.

1. INTRODUCTION

The Belgium continental shelf consists of numerous tidal sandbanks shaped by very large dunes showing various patterns. Such dynamic sedimentary structures are the result of complex interactions between the hydrodynamic and the sediment (Powell, 2000). They are of great interest for various end-users: while mobile dunes represent navigational hazards for hydrographers, due to their important volume of sand, they contribute significantly to the economic resources available for the dredging industry.

The modeling of sand dunes evolution is necessary for both scientific and practical purposes, but up to now, processes controlling their dynamics still remain far from perfect (Franzetti et al., 2013). In parallel to theoretical and numerical approaches developed to explain the generation and the evolution of the sand dunes, morphometric approaches propose a geometrical reading of these bedforms to describe the local hydrodynamic and sediment dynamic processes within a zone of interest. Current approaches extract structural lines by mimicking manual processes or simplifying the sand dunes shape. Such manual digitalization is usually performed individually for each dune.

In contrast to these approaches, we developed a 3D semi-automatic and global method operating on a bathymetric TIN. The extracted primitives are the salient ridges of the sand dunes and the valley lines between the sand dunes. The originality of our approach lies in the use a mesh data structure to represent the sand dunes as surfaces, their analysis through geodesic morphometry and their quantitative description using 3D parametric curves. This paper describes the application of this original approach on a real dataset acquired on a zone shaped by very large dunes located on the Middelkerke bank. The technical description of this new processing tool will be made available elsewhere.

2. DATASET DESCRIPTION

The zone of interest is the reference zone R2 located on the northern part of the Middelkerke bank. This tidal bank has been studied for many years. Its morphological and hydrodynamical setting is described in (Lanckneus et al., 1994; Lanckneus and De Moor, 1995).

As displayed in Figure 1, the North West (NW) part of R2 area is located on the summit of the bank while its South East (SE) part lies on its flank. The low water depth of R2 varies from 8 m on the north to 14 m on the south. R2 area is shaped by very large dunes which are themselves modeled with transversal superimposed medium to large dunes (according with the dune classification of Ashley (Ashley, 1990)). Very large dunes height observed on R2 are between 1 to 4 meters height with a wavelength ranging from 50 m to 100 m. The crest lines of the very large dunes are mainly North-South (NS) oriented. The very large dunes of the NW part are nearly straight to slightly sinuous in the SE part. The anastomotic pattern of the crest lines located in between may be explained by residual tide currents operating in opposite direction in the NW and SE parts of R2.

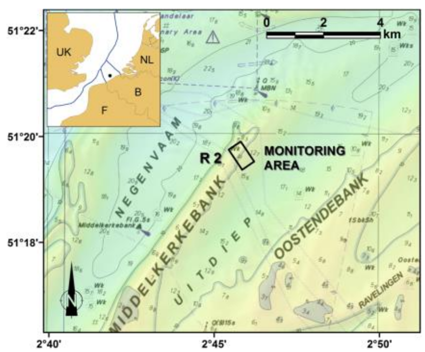

Figure 1: Location of monitoring area R2.

The local and temporal variability of the dune pattern is described by repeated bathymetric surveys. MBES data are available for a period starting from 2000 at a frequency of at least two surveys per year (Cf. Table 1). Data were acquired using a SIMRAD EM1002 and a EM3002D after 2008. Both MBES systems were installed onboard the research vessel Belgica (Degrendele et al., 2014).

3. GEODESIC MORPHOMETRY

3.1 3D global semi-automatic approach steps

A close look at the raw data displayed in Figure 2(a) points out the transversal superimposition of medium to large dunes on the very large dunes main pattern. When the extraction of salient ridges and valleys are of particular concern, the main difficulty lies in the elimination of the medium to large dunes that are found to heavily overprint any observations. To this end, the anisotropic filter, which is applied first, enhances the dominant features while smoothing the secondary ones (see figure 2(b)). The availability of this efficient filter opens the door to the explicit extractions of both valley and crest lines of the very large dunes through a robust and automatic process.

This extraction procedure basically built on high level transforms of the Mathematical Morphology makes use of a saliency indicator that is built from an *ad hoc* analytical recombination of the curvature coefficients. The map presented in Figure 2(c) displays sharp ridges (*resp.* valley) through a large positive (*resp.* negative) magnitude value in red (resp. blue) color – see also Table 1 for the other surveys. The last step consists of extracting the ridge and valley lines from the saliency map. The resulting global network is depicted in Figure 2(d). Lines are displayed using an ad-hoc iconographic representation enabling to assess their characteristics through their color texture and section radius.

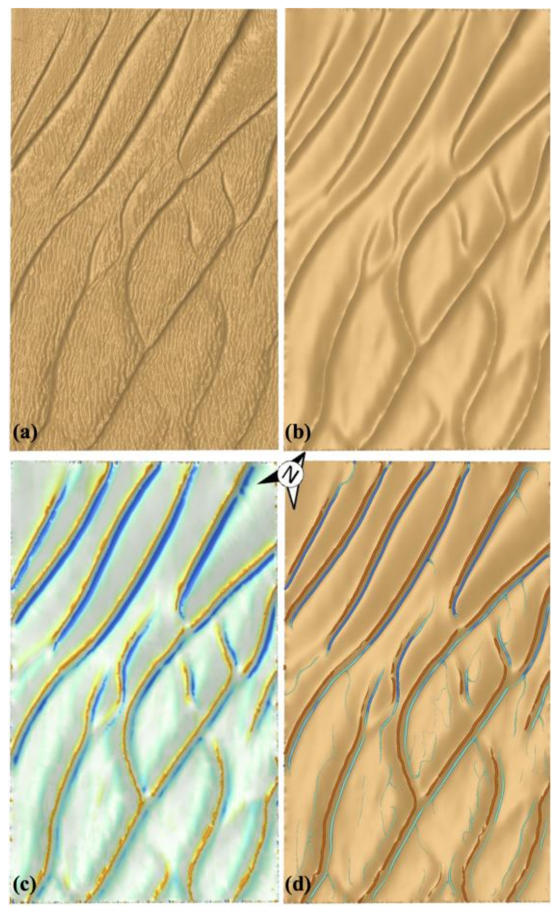

Figure 2: The four steps of the geodesy morphometry analysis applied to R2 (2014/03/14): (a) raw data ; (b) anisotropic filtering; (c) Saliency indicator mapping; (d) ridge and valley network of the filtered TIN.

3.2 Morphodynamic description of R2

The time evolution of R2 is described in Table 1. The adaptive scale of the saliency indicator demonstrates the variability of very large dunes geometry during these thirty bathymetric surveys that were acquired at different tide levels.

Examples displayed in Figures 3 were chosen according to the features of their ridge and valley networks. In 2010, the very large dunes located in the NW part of R2 are symmetric regarding the distance separating adjacent valley and ridge lines, while those belonging to the SE part are asymmetric (the lee side pointing in the SW direction). Whereas a subsequent 2014 survey shows the opposite situation with the asymmetry of the very large dunes in the NW part of R2 area while very large dunes of the SE part are quite symmetrical.

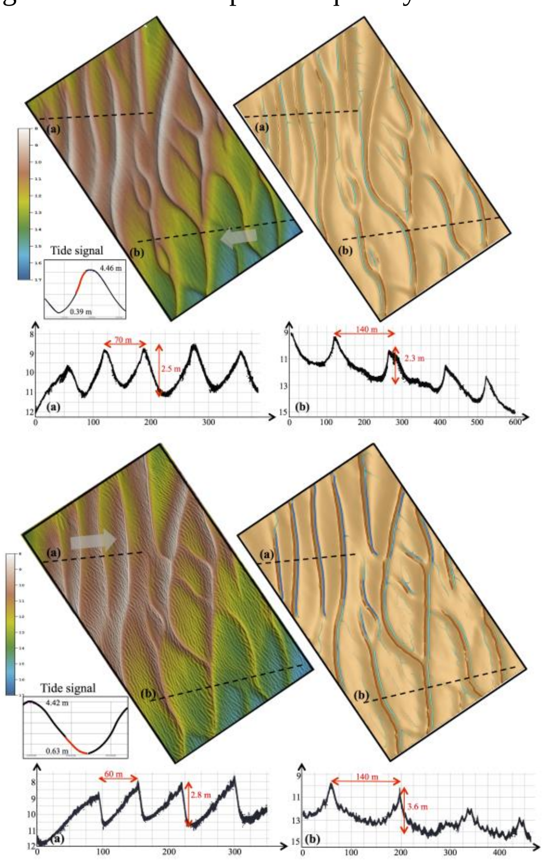

Figure 3: R2 bathymetry (top: 2010/09/06, bottom: 2014/03/14) with its ridges and valleys network and two bathymetric profiles.

The augmented database now includes a smoothed and parameterized 3D curve linked with each path. A representation of one of these structures is given in Figure 4. The latter should enable to build *ad hoc* path statistics at convenience.

4. PERSPECTIVES

A 3D global method based on bathymetric TIN is developed in order to extract and digitize semi-automatically the dune pattern in a given area. These reliable high level measurements could help marine scientists insert relevant global constraints into their complex models to calculate advanced results with tractable computational costs.

Based on the 3D vectors resulting from this approach, 3D augmented representation can right now assist geoscientists in tracking dunes morphology and dynamics. However, a network tracking tool should be specifically developed to easily assess the magnitude and direction of the dunes movement. Incoming works will also track the volume of sand involved in the dune dynamics.

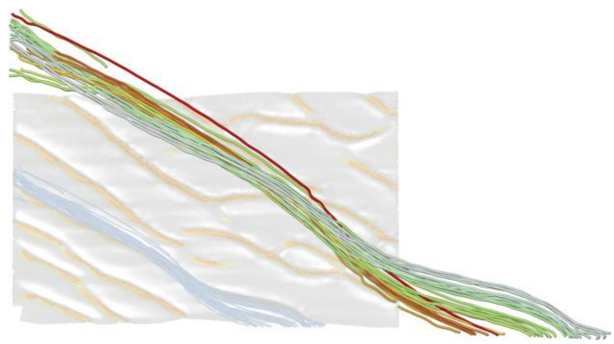

Figure 4: Merging of the noodle 3D representations of one very large dune crest over time. The colors are made to both shift and unsaturate linearly w.r.t. time.

5. REFERENCES

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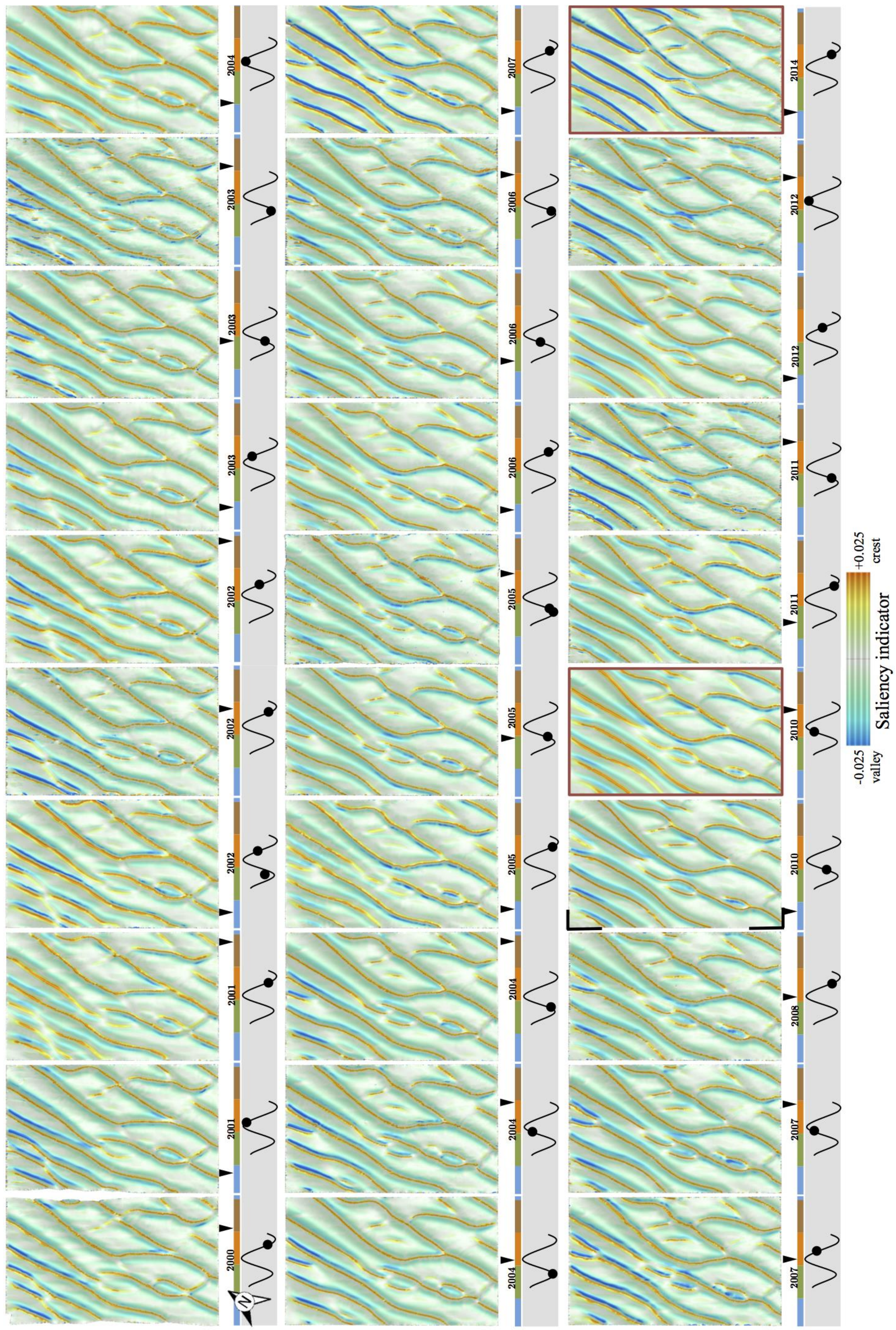

Table 1: Mapping of the saliency indicator on a sequence of thirty filtered instances of the R2 monitoring area. Dates of MBES data acquisition together with tidal level at survey time are displayed.