DETECTION OF SALIENT FEATURES IN SURFACE CURRENT MAPS FROM DOPPLERIZED X-BAND RADAR

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1. INTRODUCTION

Horizontal surface current fields were mapped in a tidal channel of the North Frisian Wadden Sea (Germany) measuring the Doppler frequency shift from scatterers on the rough water surface using dopplerized nautical X-band radar (RDCP, Radar Doppler Current Profiler) [1]. Data sampling from a moving boat allowed the nearly synoptic coverage of a some square kilometer area with a horizontal cell resolution of $15m \cdot 15m$. The horizontal surface currents exhibit a modulation in magnitude from 0.8 to 1.4 ms^{-1} at full tidal current. This pattern can be qualitatively related to the presence of sea bed dunes of 150 m length and 5 m height that were mapped by means of multibeam echosounder technology. Technically, the digital terrain model of the bathymetry represents a one-channel image with the scalar quantity water depth, and the horizontal surface current vector map a two-channel image. Image processing tools were applied to characterize quantitatively the patterns of both the current velocity and bathymetry in a consistent way. To illustrate the potentials of image processing, the structure tensor method was used to detect the location and orientation of edge-like structures and their orientation of both sea bed and current fields as an approach to analyse in situ the current-sea bed interaction in all spatial dimensions.

2. SETTING

The field survey was carried out during May 2007 in the Lister Deep, Northern Germany, the only sea gate between the back barrier island Sylt-Romo basin and the North Sea. The water depth in the deep is up to $35m$, the tides are semidiurnal with an average range of $2m$. At full tide, current velocities amount up to $1.5ms^{-1}$ in the centre of the deep. The bed topography is characterized by dunes that range up to $150m$ in length and $5m$ in height. Safety considerations and operation constraints for both the Dopplerized radar and multibeam systems allowed crusing of the research vessel only during moderate wave conditions. A $2000m \cdot 400m$ subarea parallel to the channel axis was mapped at two occasions. For the radar measurements, the survey lasted 30 minutes during full tidal current, thus reveiling an approximate steady tidal situation. The multibeam survey was performed ten days later. From comparison of different surveys an along-channel dune movement of $10 - 15m$ per month was estimated. Thus the 10 day displacement of the dunes is well below the $15m \cdot 15m$ cell resolution of the RDCP current mapping.

3. METHODS

3.1. RDCP Data Processing Methodology

An overview over a ship based RDCP installation and the processing scheme is outlined in Fig. 1. The main hardware components are two Dopplerized radars with the VV antennas pointing perpendicularly to each other, a navigation system who acquires the ship's position, heading, pitch and roll and an ADCP. The first processing step is the extraction of the radial

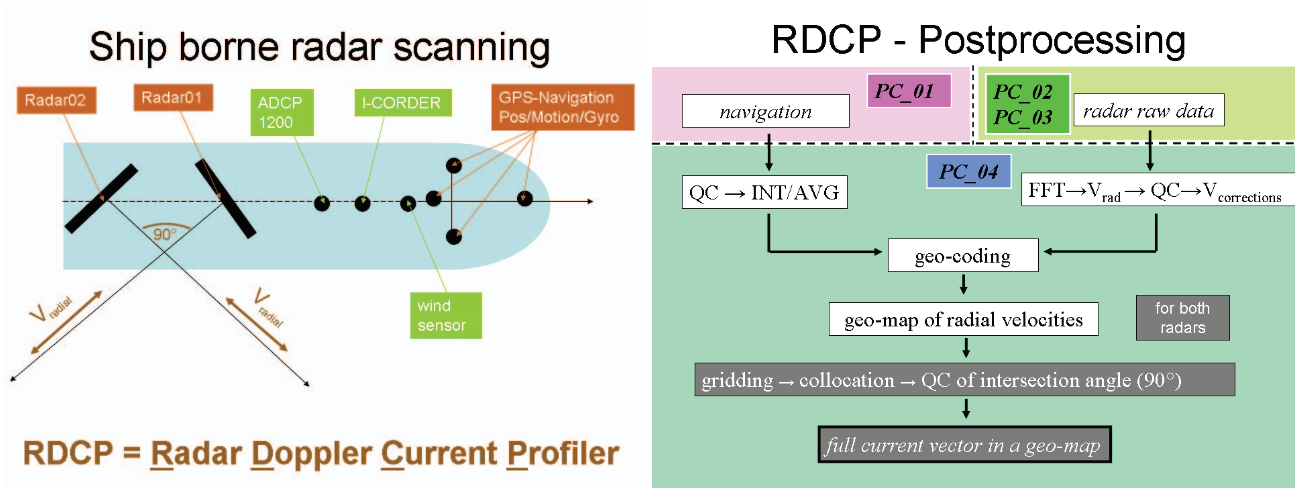

Fig. 1. Scheme of instrumentation on board of a ship for RDCP data acquisition (left) and the processing scheme (right).

velocities of the scatterers from the Doppler spectra. After correctiong for the Doppler shift induced by the ship's movement the measurements have to be corrected by the intrinsic speed of the scatterers and the influence of the wind drift. These influences are parametrized by calibration measurements in homogeneous sea areas with the ADCP mounted vertically on the ships floor as the ground truth current sensor. A more detailed outline of the RDCP methodology is given by [2].

3.2. Image Processing Methods

Image processing methods are previously applied to digital terrain models from multibearm echo sounders [3]. The parameters this software provide are the detection and the determination of orientation, length scale and spatial shift during time steps of salient features, i.e. sand ripples and dunes. One popular procedure to detect local structures in images and to estimate their orientation angle is the structure tensor method [4]. An extension to multi-component images is given by [5] in the context of color image processing for multimedia applications. The structure tensor $\mathbf{J}$ is a 2x2 matrix:

$$\mathbf{J} = \begin{pmatrix} j_{xx} & j_{xy} \\ j_{yx} & j_{yy} \end{pmatrix}. \tag{1}$$

Its components are calculated using the following formula:

$$\mathbf{J_{pq}} = \mathbf{B}(\mathbf{D_p} \cdot \mathbf{D_q}), \qquad (\mathbf{D_p} \cdot \mathbf{D_q}) = \sum_{\mathbf{i=1}}^{\mathbf{N}} \frac{\partial \mathbf{g_i}}{\partial \mathbf{p}} \cdot \frac{\partial \mathbf{g_i}}{\partial \mathbf{q}} \tag{2}$$

where $\mathbf{B}$ is a binomial smoothing filter and $\mathbf{D_p}$ and $\mathbf{D_q}$ denote a derivation filter applied to the image in the coordinate directions. Thus, the pq-component of the structure tensor, $\mathbf{J}$, is calcualted by convoluting the image components g_i independently with $\mathbf{D_p}$ und $\mathbf{D_q}$, multiplying the resulting images pixelwise and smoothing the outcome with the binomial filter, $\mathbf{B}$. Structure, i.e. local spatial variation of the pixel values can be quantified by an Eigenvalue analysis of the structure tensor (Eq. 1), giving the eigenvalues (λ_1, λ_2) and the eigenvectors $(\vec{e}_1, \vec{e}_2)$. Because the structure tensor is symmetric both eigenvalues are zero or positive real numbers. If both eigenvalues are close the zero the local neighborhood has constant values. If both eigenvalues are positive the pixel values change in all directions. The case relevant for the detection of edges is that one eigenvalues is close to zero the pixel values do not change in the direction of the eigenvector corresponding to the zero eigenvalue. The local neighborhood is a simple neighborhood with ideal orientation. The direction angle of the tangent, termed the orientation angle

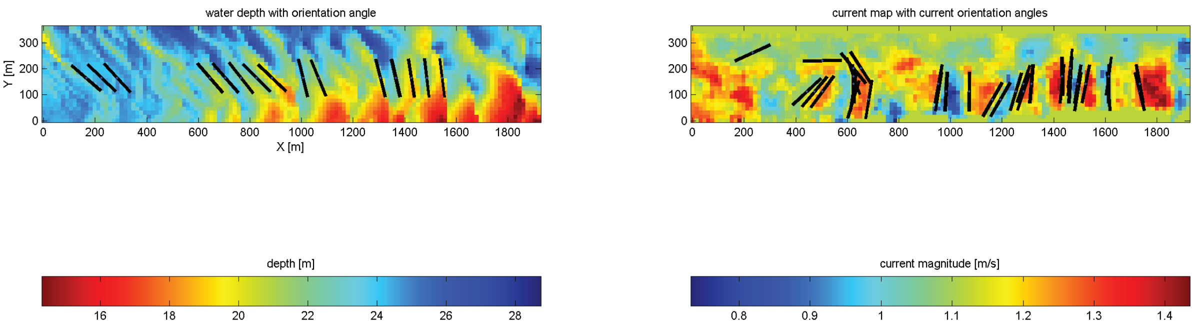

Fig. 2. Digital terrain model retrieved from multibeam echosounder with the detected depth edges overlayed (left). Magnitude of surface current with the detected current edges overlayed. The current edges are retrieved from the surface current vector (right).

Φ, and the orientation coherency c are given by

$$\tan 2\Phi = \frac{2\mathbf{J_{xy}}}{\mathbf{J_{yy}} - \mathbf{J_{xx}}}, \quad \Phi \in] -\frac{\pi}{2}, \frac{\pi}{2}].\, quadc = \begin{cases} (\frac{\lambda_1 - \lambda_2}{\lambda_1 + \lambda_2})^2 = \frac{(\mathbf{J_{yy}} - \mathbf{J_{xx}})^2 + 4\mathbf{J_{xy}^2}}{(\mathbf{J_{yy}} + \mathbf{J_{xx}})^2} & \text{if } (\lambda_1 + \lambda_2) > 0 \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

4. RESULTS

Fig. 2 shows the maps of water depth and current magnitude. For consistency the finer bathymetry map was mapped onto the $15m \cdot 15m$ grid of the RDCP analysis. The large bed dunes are clearly visible and position and orientation of the crests identified in most cases by the structure tensor method. The current fields show a modulation in magnitude that obviously resembles the sea bed topology in the middle end eastern part (x $>$ 600 m), although the algorithm did identify more salient structures here. This may be due to the fact that the two coherency thresholds for selecting the edges do not consistently mirror the fact that the edges are more pronounced in the digital terrain model than in the current map in the algorithm now implemented. The current modulation is most likely due to the flow continuity through the varying cross sections of the water column. This hdyrodynamic interaction of surface current with bottom topography was already indirectly observed in a modulation of the normalized radar cross section [6]. With the RDCP, however, this effect can be observed directly [7]. It shows up also in the vertical current component (s. Fig. 3). In the western part, the orientation of the current ”edges” is nearly perpendicular to the bed dunes. A thorough topological analysis of bathymetry and current features is presently under investigation.

5. SUMMARY AND OUTLOOK

The mapping of the near surface currents and their interaction with the spatial and temporal varying bottom topography is of high significance for the experimental analysis of morphodynamic processes in coastal areas and the monitoring the effectiveness of coastal protection actions. An efficient application is also the real-time monitoring of currents in harbours to pilot large vessels [8]. The next steps of this inquiry are the application of image processing methods to extract also, together with the orientation, length scales and spatial shifts of salient current features. The correlation with salient features of the bed topography will be analyzed further together with sea state images that can also be deduced from radar data.

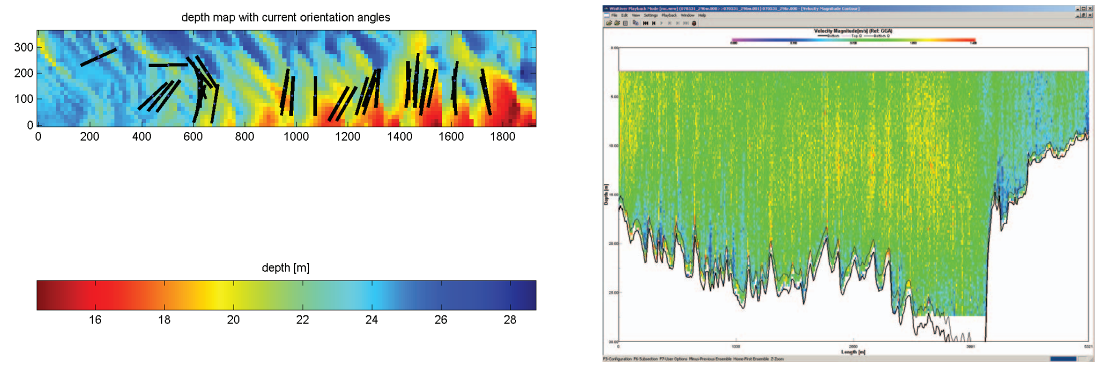

Fig. 3. Digital terrain model with the current edges detected on an RDCP current map overlayed, demonstating the influence of bottom on the surface current (left). ADCP vertical current profile, showing hydrodynamic modulation (right).

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