Data analysis of sand waves in the North Sea.

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Abstract
Monitoring of the sand wave covered bathymetry near the entrance channel to Rotterdam harbour resulted in detailed information on the sand wave field. These data are analysed using a 2 dimensional spectral analysis. Here, the first results are presented.
The surface has a very complex structure, which is however, nothing else than the result of three different waves. The smaller waves appear to be very sensitive to the presence of larger waves. The wavelength of the waves depends on the local water depth. This is in agreement with most theoretical models, which use a scaling with the depth to get a uniform wavelength. This dependency results in a number of different patterns, ranging from very complex 2 dimensional patterns to fairly regular sand waves with a sinusoidal crest.

Introduction

Near the entrance of the navigation channel to Rotterdam harbour (see Fig. 1), a sand wave field is present. These sand waves have a wavelength varying between 500 m en 1 km, a height of 5 to 10 meter, and their crests are approximately rectangular to the principal direction of the tide. Since these sand waves reduce the navigability, the Dutch department of public works is monitoring their behaviour. This resulted in detailed information on the bathymetry of the wave field, in an area of about 225 squared kilometres over a period of 8 years.
To predict the future behaviour of sand waves, researchers are interested in the theory on the formation of sand waves. Most theoretical models assume sand wave with a straight or slightly sinusoidal crest, for simplicity. Base on physical knowledge, a model is then derived (Hulscher, 1996 ; Komarova and Hulscher, 1999). However, in reality such regular sand waves are rare.
In this study, the measurement data in the North Sea area are analysed. The found patterns are then reproduced using linear waves superimposed on each other. This would link the relative models of linear patterns to the very complex patterns that are found in reality.

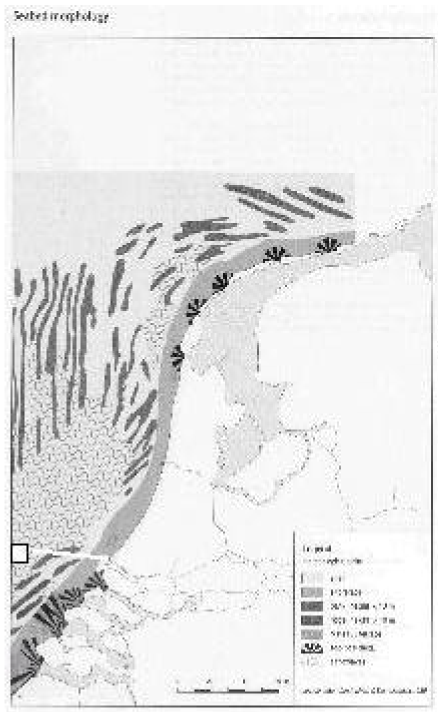

Figure 1: Measurement area (white square) near the entrance channel (white line) to Rotterdam harbour. (Original picture by Van Alphen and Damoiseaux, 1989)

1-Monitoring of the bathymetry in the North Sea .
In the North Sea sand waves are present in the navigation channel to Rotterdam harbour. To maintain the navigation depth, dredging takes place if the depth is less then a reference depth. To check the depth, detailed bed level measurements are taken once a year.

This monitoring of the bathymetry near the navigation channel to Rotterdam harbour resulted in a huge data set, which covers approximately 225 squared kilometres and 8 years. The whole area is covered with sand waves. The bed level was measured using echo soundings. At first the depth was measured with single beam sonar giving a resolution of 10x75-squared meter, later a multi beam sonar was used, giving a resolution of 10x10-squared meter. The measurement frequency is once a year, although in some years no measurements were taken.

In the area the water depth varies between 27 and 49 meter, the tide is almost unidirectional with a 30 degrees clockwise angle to the north. The amplitude of the tide is approximately 0.65 m/s. The median grain size is somewhere between 250 and 350 μm with a steep gradient from east to west (McCave, 1971). The resulting bathymetry is given in Fig. 2.

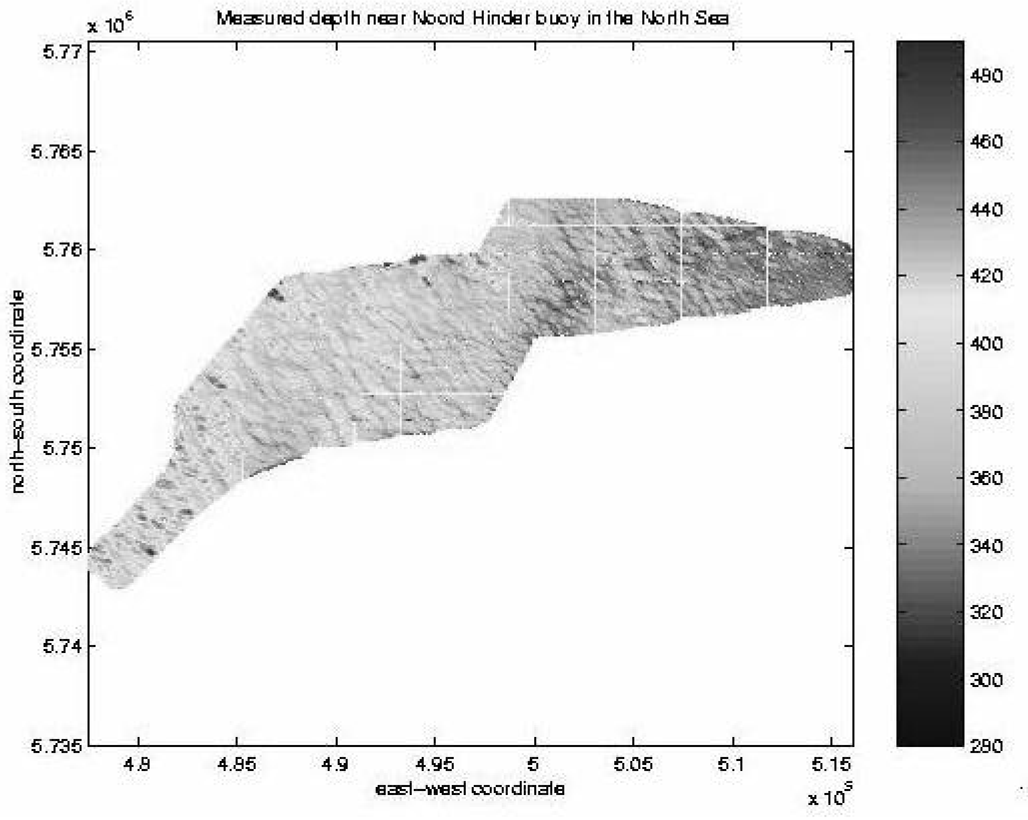

Figure 2: Bathymetry measured in 1990.

2-Data description
The bathymetry of the measurement area is fairly flat, with an average depth varying between 40 m in the west to 32 m in the east. In these areas, there are three different large wave patterns. The smallest can be classified as sand waves. They have a wavelength of approximately 600 meters, and the crests are perpendicular to the direction of the principle tidal currents.

The second pattern has a wavelength of about 1700 meter, and the crests are at an angle of about 70 degrees counter clockwise to the direction of the principal tidal current. This pattern is only visible in some parts of the domain. It appears to be non-existent in the other areas.

The largest waves can be classified as tidal sandbanks. They have a wavelength of about 5 kilometres, with the crests at a small angle counter clockwise to the direction of the principal tidal current. These are probably the edges of the sandbanks found near the Belgium and southern Dutch coast (Dyer and Huntley, 1999). However, spectral analysis results in a signal with these characteristics (see section 3).

3-Data analysis.

The data of the five areas in the domain is analysed using a 2 dimensional spectral analysis. This results in knowledge on wavelength, energy and direction of present wave structures in the data. In all five areas the same waves are present. The main difference is the intensity of the different waves. There are two distinct indications for interference of the waves.

First, the energy of the sand waves is spread over a large region in the power spectrum, when the energy of the longer waves is high. Apparently, the presence of the larger waves influences the sand waves. In the surface plots, one can see, that at the crests of the larger waves, the orientation of the sand waves is about equal to the orientation of the larger waves, while in the troughs of the larger waves, there is a clear angle between both directions.
Second, the magnitude of the intermediate waves depends on the position on the sandbanks. In the trough of the bank the intermediate waves are high, while on the crest the amplitude is less.

4-Modelling the data

From the results of the data analysis, it can be assumed that the patterns measured are a result of three waves superimposed on each other. As noticed, the smaller waves are influenced by the larger waves. Both the wave height and the wavelength depend on the local depth, which is determined by the mean depth and the larger waves.

To reproduce the measurement data, a descriptive model based on three linear waves is defined:

$$
\begin{aligned}
z_b &= HZ_0 + H(1-Z_0)Z_1 + H(1-Z_0)(1-Z_1)Z_2) \\
Z_i &= A_i \cos\!\left(\tfrac{2\pi}{L_i}\left(X\cos(\alpha_i) + Y\sin(\alpha_i)\right) + \varphi_i\right) + h.o.t.
\end{aligned} \qquad (1)
$$

with z_b the bed perturbation from the mean depth H. Z_0, Z_1, Z_2 are the tidal sand banks, large sand waves and small sand waves, respectively, as fraction of H. $A_i, L_i, \alpha_i, \varphi_i$ are the amplitude, the wavelength, the direction and the phase lag of the waves. $h.o.t.$ denote the higher order terms, resulting in the wave asymmetry. (X_i, Y_i) are the co-ordinates corrected for the local water depth:

In eq. (1) the wave height depends on the local water depth, which includes the effects of the larger waves. If the larger waves cause the local water depth to be deeper or shallower than the mean water depth, the smaller waves will b higher or lower, respectively. However, in the data it is seen that the wavelength changes with the local depth as well. Therefore, the local wavelength L_i is defined as a function of the mean wavelength $\hat{L}_i$ and the local depth:

$$
L_0 = \hat{L}_0, L_1 = \hat{L}_1(1-Z_0)^p, L_2 = \hat{L}_2(1-Z_0)^p(1-Z_1)^p \qquad (2)
$$

in which p is the scaling parameter, which depend on the exact scaling of the horizontal length. In general $p = 1$, giving a linear scaling of the co-ordinates with the depth. However some theories use a different scaling (Komarova, 2000) resulting in different values for p.

Now, the descriptive model for he data representation is complete. There are 12 parameters in eq. (1) and 1 in eq. (2). These parameters are estimated to fit the model to the measurements.

5-Conclusions

In the North Sea bathymetry data a very complex pattern is found. However a simple model, consisting of three linear waves, superimposed on each other, give a good approximation of the data. A descriptive model is formulated, and calibrated. This model includes the interference of longer waves on shorter waves. The longer waves change the local water depth. This results in changes in both height and length of the shorter waves.

6-Acknowledgement
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