

CHAPTER 172

SEA BOTTOM TOPOGRAPHY WITH IMAGING RADAR

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ABSTRACT

Mapping sea bottom topography with imaging radars or optical sensors can add valuable information to traditional bathymetric surveys. This paper describes a series of (already performed or planned) experiments in which the Dutch Bottom Topography Group is involved. It is shown how radar and optical imagery can be used to map the sea floor.

1. INTRODUCTION

The first observation of sea bottom topography with imaging radar (Side Looking Airborne Radar, SLAR or Synthetic Aperture Radar, SAR) was made in 1969 by de Loor and his co-workers (de Loor and Brunsveld van Hulten, 1978 ; de Loor, 1981). At that time it was not understood why sea bottom topography could be visible on radar images: since sea water is almost a perfect conductor at radar frequencies, the penetration length is a fraction of the radar wave length (which was about 1 cm in these observations). Therefore the radar beam never penetrates to the bottom.

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The phenomenon received little attention until SEASAT was launched in 1978. This satellite carried among other sensors a L-band SAR. With this instrument dramatic images of sea bottom topography in the Southern Bight of the North Sea and the English Channel (Alpers and Hennings, 1984), and the Nantucket Shoals (Shuchman, Lyzenga and Meadows, 1985) were obtained. All SEASAT images revealing bottom related structures are reviewed by Kasischke et al. (1983). Also internal waves (Rufenach and Smith, 1985) and ship wakes (Vesecky and Stewart, 1982) were clearly visible on SEASAT images.

The SEASAT mission has provoked much interest, both from the experimental and the theoretical side. It has stimulated further experimental research (McLeish et al., 1981 ; Valenzuela et al., 1985, Apel et al., 1985, Chubb et al., 1989). It was also found that bottom topography is visible in the optical range (Kasischke and Tanis, 1986 ; Hennings, Doerffer and Alpers, 1988).

From these studies it appeared that sea bottom topography can be visible with imaging radar in shallow seas (maximum depth about 50 m) with (tidal) currents of 0.5 m/s or more at a wind speed between 2 and 10 m/s.

In this paper the research activities in the Netherlands are described. In section 2 the imaging mechanism is described. Section 3 is devoted to past and future experimental campaigns. In section 4 the conclusions are stated.

2. IMAGING MECHANISM

Several theories have been proposed to describe the imaging mechanism. It is now generally accepted that the mechanism consists of three steps :

- (1) Interaction between (tidal) flow and bottom topography produces modulations in the surface current velocity.
- (2) Modulations in the surface current cause spatial variations in the wind generated spectrum of water waves.
- (3) Variations in the wave spectrum are visible as modulations in the radar backscatter.

Models of this kind have been proposed by Alpers and Hennings (1984), Shuchman, Lyzenga and Meadows (1985), Holliday, St-Cyr and Woods (1986) and by van Gastel (1987). Internal waves also cause variations in the surface current, so the second and third step of this mechanism can be used to describe their signature on radar images. The mechanism also applies to other regions than the microwave part of the electromagnetic spectrum.

The first step is usually described using the continuity equations (mass conservation)

$$U_{per} = C_{per}/h \quad , \quad (1a)$$

$$U_{par} = C_{par} \quad , \quad (1b)$$

where U_{per} stand for the component of the surface current perpendicular to the (elongated) sand bank or sand wave, U_{par} for the parallel component and h for the depth, C_{per} and C_{par} being constants. Equations (1a) and (1b) are in general valid for the depth averaged current velocity, but not for the surface current velocity which also is influenced by the wind. A better description of the surface current field can be obtained from a (quasi) three-dimensional flow model.

The second step, the wave current interaction or hydrodynamic modulation, is described by the Action Balance Equation. This is a transport equation with a source term describing the combined effect of wind input, dissipation and non-linear wave-wave interactions. The precise form of this term is not well known. Therefore most authors use simple relaxation forms for the source term, which is either linear (Alpers and Hennings, 1984 ; Holliday, St-Cyr and Woods, 1986 ; Hennings, 1990) or quadratic (Shuchman, Lyzenga and Meadows, 1985) in the action spectrum. Van Gastel (1987) includes the effects of wind input, dissipation and non-linear interactions in a rigorous way.

The scattering of radar from the ocean surface is usually described with first-order Bragg scattering. In this approach, the radar cross section of the sea is proportional to the spectral density at the so called Bragg wave number k_B , given by

$$k_B = 2k \sin(\theta) \quad , \quad (2)$$

where k is the wave number of the incident radiation and θ the angle of incidence.

Vogelzang (1989) has compared these models by solving the action balance equation numerically, showing that these models give almost the same results. At high radar frequencies (X-band) and at wind speeds exceeding 5 m/s or more, the effect of advection can be neglected as in the original model of Alpers and Hennings (1984). In this case, the radar cross section is proportional to the gradient of the surface current, or, using the continuity equations (1a) and (1b), to the bottom slope.

At L-band, the simple relaxation models predict modulations of the order of 10 per cent, in agreement with the experimental data. At X-band, however, these models underestimate the modulation by an order of magnitude. By including non-linear interactions (van Gastel, 1987) or other scattering mechanisms than first-order Bragg (Holliday, St-Cyr and Woods, 1986) the modulation is increased to its correct value.

3. EXPERIMENTS

In this section the research activities of the Dutch Bottom Topography Group will be described. The group is formed by representatives from Rijkswaterstaat, Delft Hydraulics, Physics and Electronics Laboratory TNO and National Aerospace Laboratory NLR. International cooperation has been established with institutes from Germany, the United Kingdom and the United States of America.

3.1 DDSLAR

A first experiment was performed on January 19, 1988 using the Dutch Digital SLAR (DDSLAR) to investigate the possibilities and limitations of mapping sea bottom topography with imaging radar for cartographic purposes. The experiment was performed in a test area 30 km off the Dutch coast (see figure 1). The bottom topography in this area is dominated by sand waves with a height between 2 and 6 m and a crest-to-crest distance of typically 500 m at a mean depth of about 22 m.

This area was chosen for the following reasons :

- (1) the bottom topography is simple and quasi one-dimensional.
- (2) the access time to the test area is short.
- (3) it is close to the Measuring Platform Noordwijk (MPN), an oceanic research platform that is part of the North Sea Monitoring Network.
- (4) the area has been studied in earlier experiments.

The test area has been recorded with the Dutch Digital SLAR, an airborne X-band HH polarized SLAR system operated by the National Aerospace Laboratory NLR. With this system and the processing facilities available at NLR it is possible to obtain both geometrically and radiometrically correct images. During the experiment the current velocity profile was measured from two ships near the centre of the test area. The position of one of these ships was recorded using HYPERFIX with a precision of 1.5 m. Therefore the image of this ship could be used as a position fix, and the position in the radar image could be determined with an

error of two pixel sizes (30 m) at most. An ordinary bathymetric map of the test area has been digitized.



Figure 1. The test area off the Dutch coast.

During the experiment, the wind speed varied between 7 and 8 m/s, while the surface current during the radar overflights was between 0.6 and 0.8 m/s. Under these circumstances one expects that the bottom slope is visible on the radar images. Figure 2 shows a radar image, a simulated radar image using the model of Alpers and Hennings (1984) and the bathymetry of the test area. The radar image is rather noisy due to the low sensitivity of the DDSLAR.

Figure 3 shows the correlation between the intensity and the bottom slope, which should have a minimum at $j = 0$ if the radar cross section is proportional to the bottom slope (note that the constant of proportionality is negative).

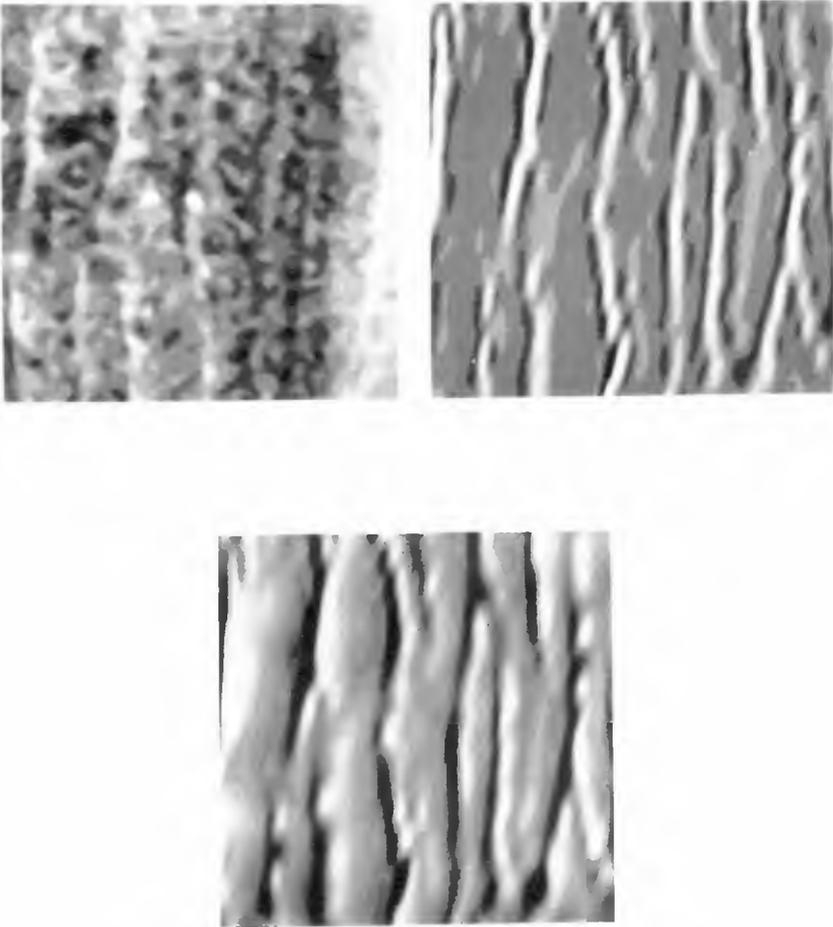


Figure 2. Radar image (upper left), simulated image (upper right) and bathymetry (lower).

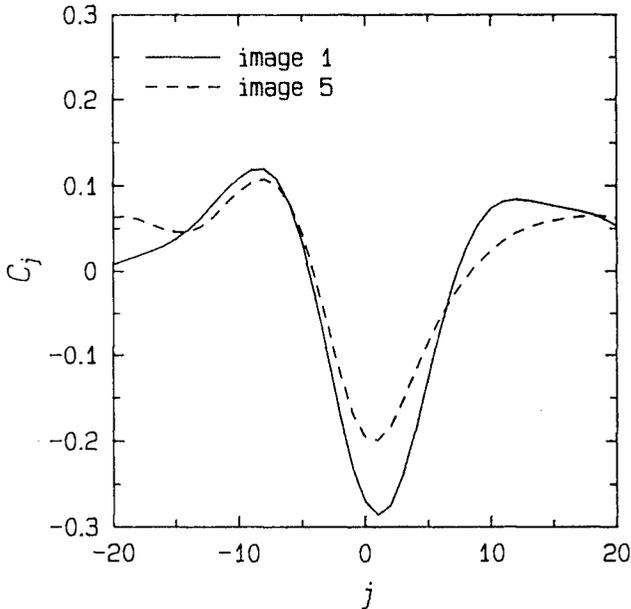


Figure 3. Correlation between intensity and bottom slope for two of the radar images recorded during the experiment

From this experiment the following conclusions were drawn :

- (1) At wind speeds of 5 m/s or more, X-band radar imagery shows the bottom slope, as predicted by simple relaxation models. The sand waves in the test area have an asymmetric profile, with the steeper slopes directed to the NorthEast. Therefore the steeper slopes are visible as a pattern of bright or dark lines, depending on the direction of the tidal current, while the gentle slopes act as a background.
 - (2) The positional accuracy in radar images can be about two pixel sizes. For most radar systems this is of the order of 20 m.
 - (3) The sensitivity of the radar system is a crucial parameter for mapping bottom topography.
- More information can be found in the final report of this project (Vogelzang et al., 1989).

3.2 JPL-SAR

On August 16, 1989, the test area was recorded with the airborne P-, L- and C-band polarimetric SAR of NASA/JPL, to study the effect of radar wave length and polarization. The sand waves are clearly visible on the P- and L-band images, but not on the C-band image. This is due to the low sensitivity of the C-band SAR. These images are now under study. They will be compared with predictions of a one-dimensional model for the imaging mechanism. The surface current field in this model is generated by a detailed quasi three-dimensional flow model of the test area. The flow model includes the effect of the wind on the surface current. The action balance equation will be solved in one dimension using existing simple expressions for the source term. The radar cross section will be evaluated using a two-scale scattering model. Such a scattering model includes the effect of longer waves by integrating the first-order Bragg scattering over the tilt caused by longer waves.

3.3 Future research

The test area will be studied with the C-band SAR carried by the first European Remote Sensing satellite (ERS-1). Wind and wave data will be collected at MPN, while the surface current will be hindcasted using the quasi three-dimensional flow model. Since the ERS-1 will make images of the test area at different points in the tidal cycle and under different wind conditions, these images can be used to fix the optimum hydro-meteorological conditions for mapping sea bottom topography with imaging radar. Also the dynamical behavior of the bottom topography can be studied, since the ERS-1 mission extends over a longer period.

In collaboration with the Universities of Hamburg and Kiel (Germany) and the University of North Wales (UK) the bottom topography in the same test area will be studied using both microwave and optical sensors. The goal of this research, sponsored by the Commission of European Communities (CEC) in the framework of the Marine Science and Technology (MAST) program, is to establish how remote sensing methods can be used as input in morphodynamic models which are currently being developed. To achieve this goal, a large experiment is planned for April 1991. The model for the imaging mechanism will be extended to two dimensions. To compare the experimental results with the bathymetry, a precise bathymetric survey with a multi-beam echo sounder will be held in the test area after the experiment.

The models developed during these experiments can be tested in a region with a more complicated bottom topography during the SIR-C/X-SAR mission with multi-polarization L-, C- and X-band SAR. A preparatory flight with the airborne P-, L- and C-band SAR of NASA/JPL is planned for 1991.

The final goal of this research is to obtain information about the bathymetry from microwave (and optical) imagery, using data-assimilation techniques as indicated in figure 4. Starting with an initial guess or an old bathymetric map, the radar image can be calculated. The simulated image is compared with the observed image. By changing the input-bathymetry, the simulated image is matched to the observed image. When both images match, the input-bathymetry equals the actual bathymetry. The next MAST program would be suited for investigating this possibility.

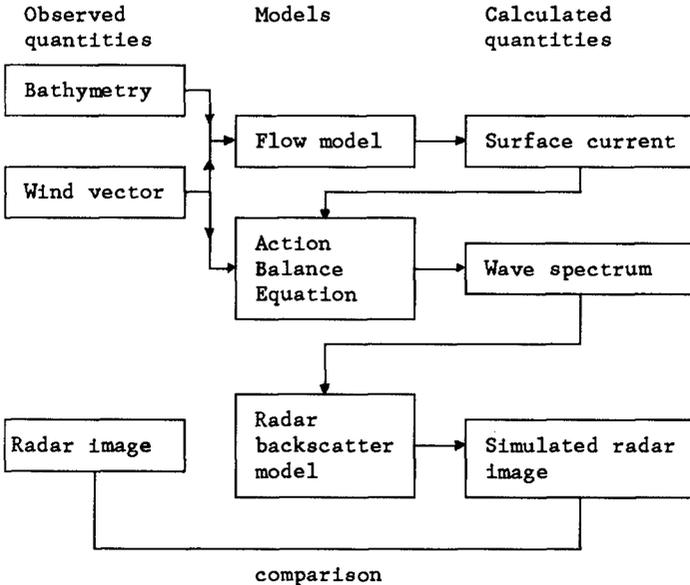


Figure 4. Modelling.

4. CONCLUSIONS

Under favorable conditions (low wind speed and strong tidal current) sea bottom topography in shallow seas can be mapped with imaging radar. At wind speeds of 5 m/s or more, X-band radar imagery reveals the region with large bottom slopes. The horizontal accuracy can be of the order of two pixel sizes, which corresponds to about 20 m for existing systems.

If the processes involved in the imaging mechanism are well modelled, data-assimilation techniques can be applied to obtain bathymetric information from radar images.

It is not expected that remote sensing methods will replace traditional bathymetric surveys. However, remote sensing methods give an overview over large areas at low costs. This information can be used for validating and steering morphodynamic models and optimizing bathymetric surveys.

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