SEAWAVE MEASUREMENTS USING A SHIPS RADAR

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ABSTRACT

The directional spectrum of a wavefield can be determined from a ships radar image with 180 degrees ambiguity. The non-directional waveheight spectrum follows by integration over all azimuth angles. These spectra are influenced by noise and interference from several sources, like speckle, wind influence and shadowing (especially at long ranges and small grazing angles).
The dispersion relation for gravity waves gives the relation between the time and spatial dependence of seawaves. The radar can be used to record dataseries in both time and place. Using the dispersion relation the data can be filtered. The resulting spectra are much cleaner and compare better with wave spectra from traditional instruments. In addition, the watercurrent and the waterdepth may be estimated.

1. INTRODUCTION

Remote sensing techniques can be used for the measurement of wavefields. Their synoptic overview form an interesting addition to the point measurements performed with wave buoys. On the other hand the imaging radar systems on airborne or spaceborne vehicles are either expensive to use or have limited periods of imaging.

For some years we have investigated the use of a simple, low cost shipsradar for the measurement of waves (1). The results of such measurements were promising, even though by lacking of other means the data had to be stored through photographing the radarscreen.

The low altitude at which the shipsradar is operated introduces some problems that usually aren't met in airborne or spaceborne applications: first of all parts of the sea surface will be in the shadow of the wave crests. This shadowing effect increases with range. Secondly, the signal to noise ratio rapidly decreases with range, thereby limiting the capability of wave measurements to rather short distances. For instance, without further improvements the radar described in (1) gave a visual range of approximately 1 km on the radarscreen.

In this paper a method is discussed to improve the results from a shipsradar. Since the radar is in a fixed position on the shore, time series can be recorded, and by proper processing, the problems can be overcome to a certain extent. In addition the combined measurement in place and time can be used in estimating watercurrent and waterdepth.

The experiments described in this paper were carried out as a small pilot study for the definition of a new, improved radar system, that will be able to measure in 3 dimensions. The small scale of this project made, that only limited surface data was available. We thank Rijkswaterstaat for kindly supplying us with their standard available surface data, recorded at platform Noordwijk.

2. THE MEASUREMENT SETUP

In this experiment a mobile X-band shipsradar, built into a car, was used. It was situated on a dune near the Dutch coast of Scheveningen. Figure 1 shows a map of the area with some of the measurement directions indicated. The properties of the radar system are given in table 1.

Table 1

frequency	: 9445 MHz
peak power	: 3 kW
pulselength	: 50 ns (7.5 m)
antenna beamwidth	: 1.2°
polarisation	: HH
data recording	
- in range	: 8 bit digital, 100 samples at 7.5 m sampling distance
- in time	: the above sampling is repeated every 1.25 sec, during appr. 20 minutes.

Although the radar is designed as a rotating beam shipsradar, we have for this experiment fixed the antenna in certain directions, as indicated in fig. 1. Instead of making an image of the area, we now receive data from the fixed line of sight only. Along this line 100 samples are taken over a range of 750 m. The distance from the radar at which the first sample is taken, can be selected. The samples are digitised and stored on a digital cassette tape unit via a controlling computer (HP-85). A block diagram is given in figure 2.

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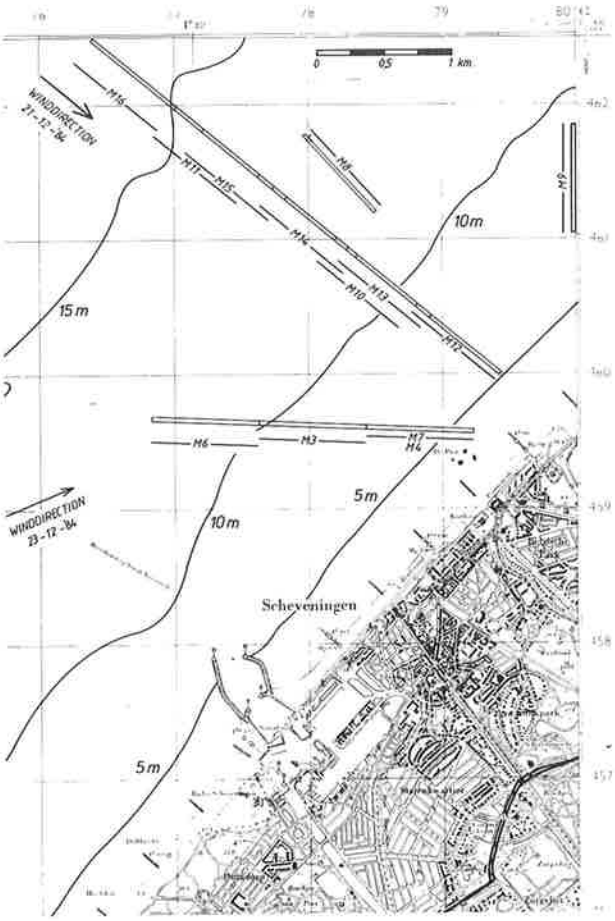

Figure 1: Map of the measurement location on the Dutch coast near the Hague, with some measurement numbers indicated.

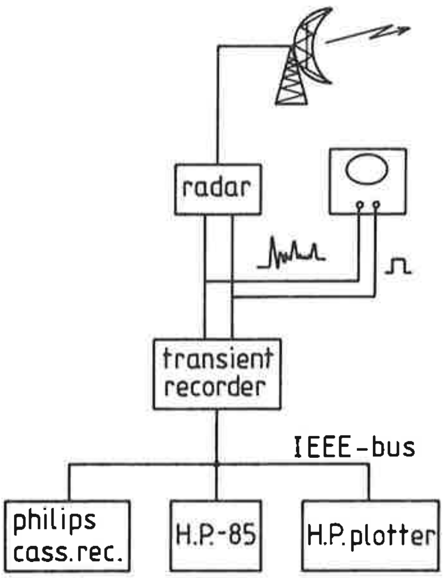

Figure 2: Blockdiagram of the measurement system.

The measurement is repeated every 1.25 second, during approximately 20 minutes. The speed and the storage capability of the computer and the tape unit forced us to this limited recording scheme. The radar PRF is much higher (2200 Hz) and if the storage capability is sufficient one could think of recording a series of 2 dimensional images instead of measurements along a line. The processing might then be done in 3 dimensions (ref. 2) instead of 2. However the present setup is capable of demonstrating the type of results that can be expected. Work is underway at the Physics and Electronics Laboratory to construct a radar system with improved properties and "3 dimensional recording", as a time series of images.

In the measurements discussed here, the antenna is pointed upwave and the measurements are made at distances between 500 m and 4.5 km. The waterdepth in this area is 5-17 m, the bottom shows gentle slopes. The nearest measured surface data comes from platform Noordwijk, at 10 km from the coast, somewhat north of this location.

The surface data consists of wave measurements only. Current measurements were not performed during this experiment.

3. DATA INTERPRETATION

An example of the recorded data is given in figure 3.

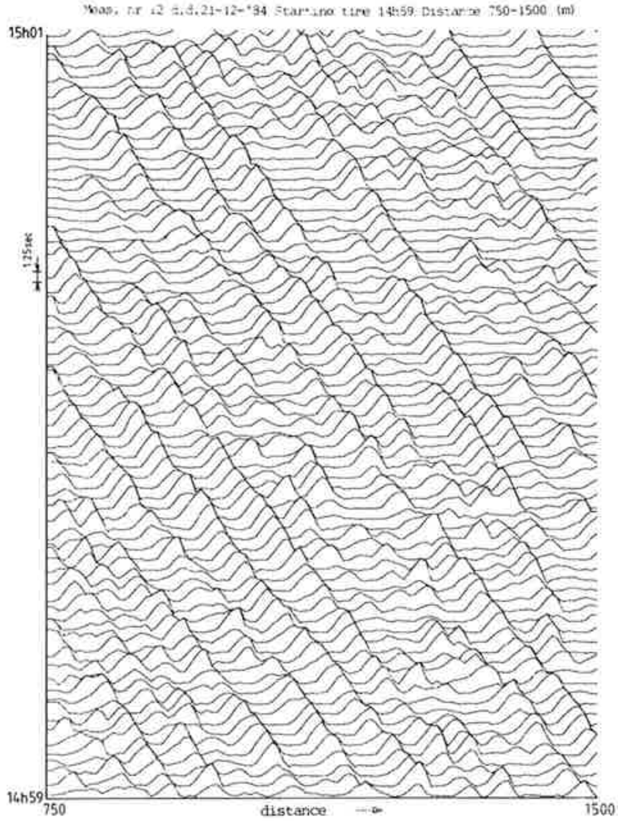

Figure 3: Plot of the recorded data in time and place.

A part (1.5 minute) of the 20 minutes time series of meas.nr. 12 is shown here. The rangewindow is set at 750-1500 m, corresponding to grazing angles between 1.5° and 0.75°. The timedifference between two lines is 1.25 seconds.

From figure 3 the average wavelength and the propagation velocity of the waves might be estimated. At longer ranges (1500 m) the influence of shadowing becomes visible. This effect is enhanced at ranges up to 4.5 km. In addition the signal to noise ratio decreases with range, as indicated before.

It is the purpose of this experiment to derive waveparameters from the radar data. Especially the waveheight spectrum is of interest. The radar spectrum produced from a data series in either time or space resembles the waveheight spectrum to a certain extent. Figure 9a shows some examples of radar spectra and the corresponding waveheight spectrum is shown in figure 9c. The difference between the spectra is believed to be caused by several effects, i.e.

- shadowing effects
- wind speed variations, resulting in backscatter variations
- non linear modulation effects of seawaves on the backscatter
- receiver noise.

We hold (one of) the first two effects responsible for the high amount of energy at low frequencies (< 0.1 Hz) in the radar spectrum. To differentiate between wave induced and non-wave induced energy in the radar spectrum we will make use of the 2 dimensional radar dataset in time and place. The measured function h(x,t) is Fourier transformed to its spectral equivalent H(k,ω).

Figure 4 shows a 3 dimensional plot of the resulting spectrum in wavenumber - frequency space.

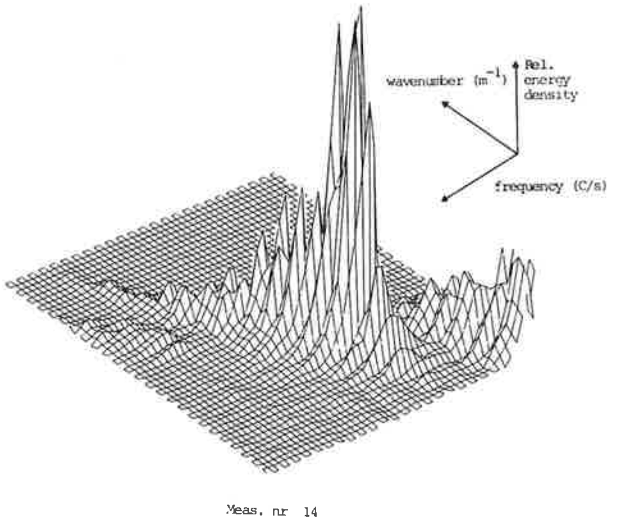

Figure 4: 3 dimensional plot of the Fourier transformed radar data in ω-k space.

The dispersion relation for range travelling waves

$$\omega = \sqrt{gk \tanh(kd)} + ku$$

with ω = frequency
g = gravity constant
k = wavenumber
d = waterdepth
u = watercurrent (in range direction)

gives a relation between the frequency and the wavenumber.

Figure 5 shows a contourplot of the spectrum from fig. 4.

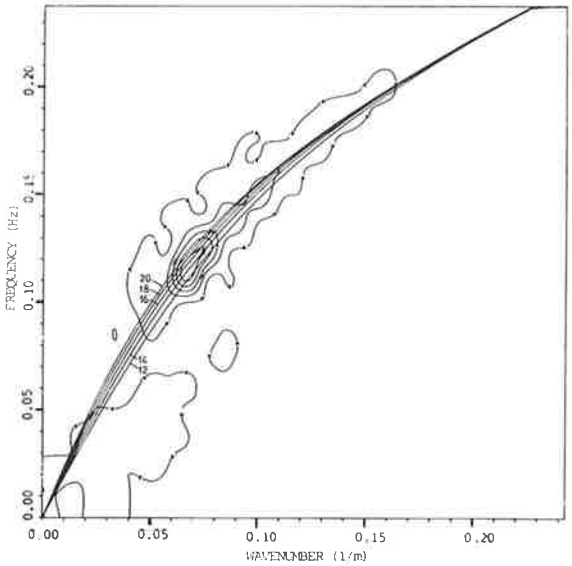

Figure 5: Contourplot of the ω-k spectrum, with the dispersion relation indicated for several waterdepths.

The dispersion relation is also plotted, with the waterdepth as parameter. Figure 6 shows a plot for the influence of the watercurrent on the dispersion function, now with constant waterdepth.

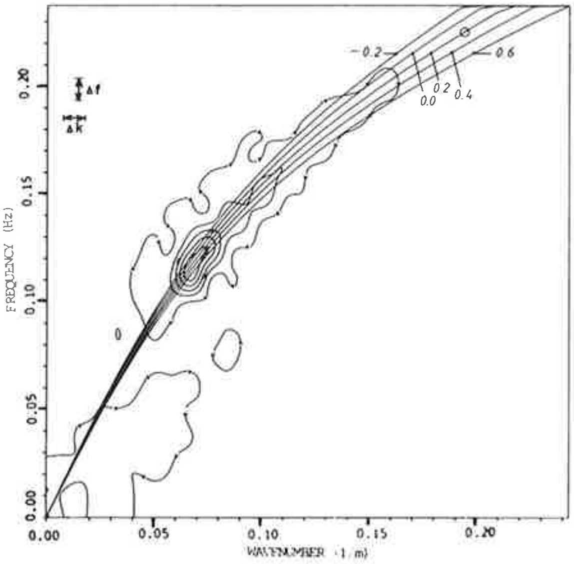

Figure 6: As fig. 5, now with the watercurrent dependence of the dispersion relation.

Since the measurement is setup along a fixed line, the radar spectrum is only influenced by the component of the watercurrent in the direction of the measuring line.

From figures 5 and 6 it can be seen that the highest sensitivity of the dispersion relation on waterdepth and -current occurs at different frequencies. The value of these 2 parameters can be determined almost independently of each other, by fitting the dispersion relation to the actual spectrum.

Finally the non wave induced energy can be eliminated from the spectrum by applying a spectral filter to the data, shaped on the basis of the dispersion relation.

4. RESULTS

The purpose of the measurements was mainly to serve as a pilot study for the further development of a ground based radar seawave sensor, with digital data processing in near real time. A relatively small number of measurements was recorded during 2 days, 23-11-84 and 21-12-84. The measuring system was setup with components that were at hand.

Some 10 cases were useful for the here presented analysis. The measurements were taken at varying ranges. The gentle slope of the seabottom therefore results in waterdepths ranging from approx. 5 to 17 m in the measurement set, as can also be seen in figure 1. The waterdepth is determined from the 2 dimensional radar spectrum, by fitting the dispersion relation to it. The resulting depths are compared to the values that are determined from a map. Figure 7 shows the correlation plot.

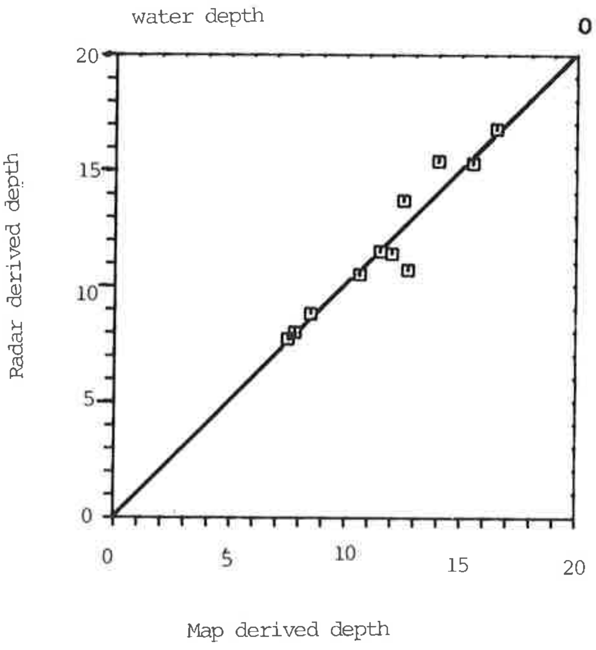

Figure 7: Correlation plot of the waterdepth as measured by the radar versus map derived values.

The values compare very well. The correlation coefficient is as high as 0.96. These results indicate that the local average waterdepth can be determined from radar wave measurements. Small scale details cannot be seen in this way because the values found are the best fit for the whole measurement cell, which has a length of 750 m.

In the same way average watercurrent values in the direction of the radar were determined. However, there are no in situ measurements available, so the values cannot be checked. Therefore these results are not presented here. We could only conclude that the values found, were not unrealistic.

In figure 8 the contourplot of a ω-k spectrum is given once more, this time with the shape of the spectral filter indicated.

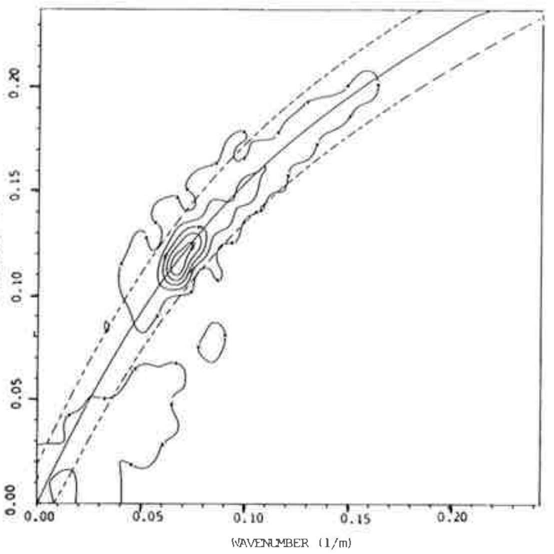

Figure 8: Contourplot of the ω-k spectrum, with the filtered area indicated.

The energy within the boundaries of the filter contributes to the filtered waveheight spectrum in figure 9b. The energy outside the filter area is described to non wave induced modulation mechanisms, like shadowing, wind influence and to electrical noise. This energy is neglected.

Especially meas.nr. 15 in fig. 9, which is taken at a distance of 3.5 km, shows a good improvement after the filtering procedure.

Although the filtered radar spectra compare better to the in situ waveheight spectra than the unfiltered ones, their shape seems still somewhat different. Based on previous experience (ref. 1) we find an even better comparison, if the radar spectrum is multiplied by f^2. This operation corresponds to taking the time derivate of the backscattered power, which for these measurements apparently better relates to the sea surface excursion. A physical explanation lacks for the time being. In ref. 1 the time derivative of the radar backscatter determined from 2 sequential radar images was used to produce a radar spectrum, which then was compared to a waveheight spectrum. In all these cases the energy at very low frequencies (< 0.05 Hz) disappears and the energy above approx. 0.15 Hz is amplified enough to compare the waveheight spectrum better.

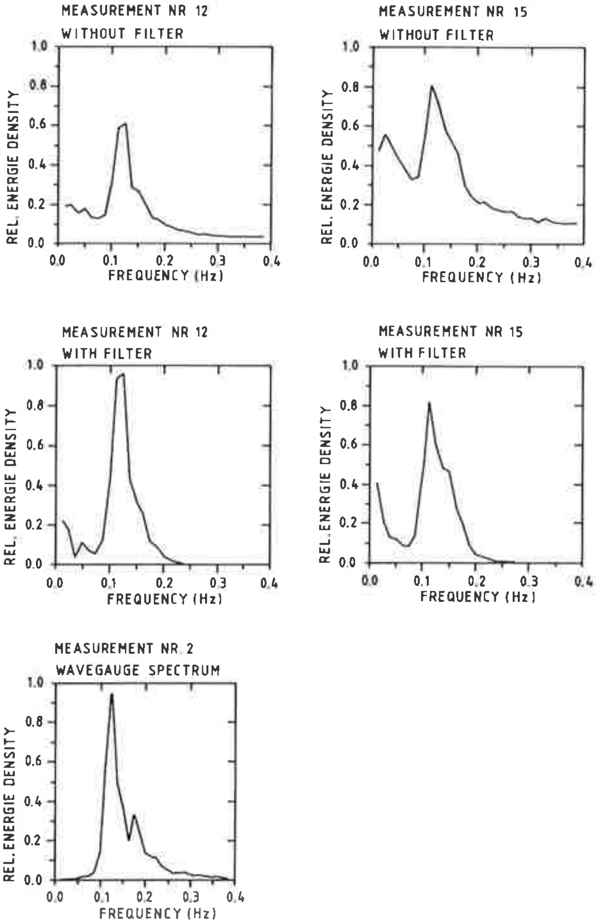

Figure 9: a. Radar derived "waveheight" spectrum for meas.nr. 12 (750-1500 m) and meas.nr. 15 (2775-3525 m).
b. As a, with spectral filter applied.
c. Simultaneously measured waveheight spectrum from platform Noordwijk (20 km north of our measurement spot, at approx. the same distance from the coast).

5. CONCLUSIONS

In this paper results are presented from a pilot study into the capabilities of a shore based shipsradar as an ocean wave sensor for short ranges up to say 5 km. The possible use of such a system could be to monitor the wave climate in complex areas and from ships and platforms. In this project radar data is recorded from a number of fixed points at the sea surface along the line of sight, during a certain time. This leads to a two dimensional dataset in time and place.

By applying a spectral filter to the Fourier transformed data it appeared possible to improve the useful measurement range of the radar. The resulting spectra fit better to a traditional determined waveheight spectrum. This fit is further improved by multiplying the spectrum with f^2, though this could not be explained so far.

The datasets in ω-k space have been used to determine average waterdepth and watercurrent in the direction of the radar by fitting the dispersion relation to the data. Only the waterdepth could be checked. A correlation coefficient of 0.96 was found.

The project learned us that our future system will benefit from a three dimensional recording in time and place (a timeseries of images). The relation between radar spectra and waveheight spectra has to be further investigated, also in the sense of predicting absolute waveheights from the radar spectrum. This seems to be the most difficult problem, which can be explained from the fact that it relies on the measurement of a modulation effect (secondary effect), whereas the other parameters could be determined from a direct effect, i.e. the measurement of the propagation speed of a wavecrest in relation to its wavelength. Furthermore the method has to be tested under varying meteorological and oceanographic conditions.

6. REFERENCES

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