Azimuthal Dependence of the Radar Cross Section and the Spectral Background Noise of a Nautical Radar at Grazing Incidence

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INTRODUCTION

The radar signal backscattered from the sea surface is a composite of speckle and the modulation due to the surface gravity waves. In the spectral domain the speckle results in a background noise floor and the modulation component in the wave signal. Both components are wind dependent. The signal to noise ratio (SNR) of synthetic aperture radar (SAR) image spectra is used for the calibration of the spectra. This method is applicable to nautical radar image spectra as well [1]. The SAR sensor detects the complex backscattered electromagnetic field. In contrast the nautical radar detects only the envelope, presented as grey levels. Furthermore the SAR operates at moderate incidence angles, while the nautical radar is scanning the water surface at grazing incidence.

Nautical radar image sequences are transformed in the three dimensional frequency-wavenumber domain. There the two components are separated with the dispersion relation of surface gravity waves used as a spectral filter. The subject of this study is to clarify the azimuthal dependence of the variation of the background noise in the spectral domain and the radar backscatter in the spatial domain. The results obtained from the nautical radar are compared to the C-band model (CMOD_IFR2), which is used to determine wind fields over the ocean with the scatterometer and the SAR with vertical polarisation.

THEORETICAL BACKGROUND

The noise of radar images caused by the stochastic interference between electromagnetic waves, backscattered from single scatterers in the radar resolution cells, is called speckle. The backscattered field can be represented as the product of the speckle component and a function, which describes the modulation of the radar return by long surface gravity waves [2][3]. The modulation signal of the surface waves E_{sig} is given by

$$E_{sig}(\vec{k}) = |M|^2 < \sigma_0 >^2 k^\beta E_w(\vec{k}), \quad (1)$$

with the wave spectrum E_w, the non-dimensional modulation transfer function M, and the normalized radar cross section σ_0. The brackets $< \dots >$ denote ensemble averaging over the large scale wave field. For tilt spectra the value of the exponent β is 2. At grazing incidence the waves are imaged by shadowing and the value of β is 1.2. For radar images with non-overlapping resolution cells, the speckle results in a white floor of the radar image spectra. If the pixel size is equal to the size of the radar resolution cells, the spectral density of the speckle noise floor will have the magnitude

$$E_n(\vec{k}) = < \sigma_0^2 > \rho_a \rho_g, \quad (2)$$

with the ground range resolution ρ_g and the azimuthal resolution ρ_a. For a Gaussian backscattering surface, the relation

$$< \sigma_0 >^2 = < \sigma_0^2 > \quad (3)$$

holds, and the SNR is given by

$$\frac{E_{sig}(\vec{k})}{E_n(\vec{k})} = \frac{|M|^2 k^\beta E_w(\vec{k})}{\rho_a \rho_g}. \quad (4)$$

From the SNR, the calibrated surface wave spectrum E_w can be obtained [3]. In contrast to the modulation signal and the noise level the SNR is independent of the normalized radar cross section (NRCS) and therefore of the wind vector. The calibration method was already used for SAR image spectra [4]. It was shown empirically, that the method is also applicable to three dimensional frequency-wavenumber spectrum obtained from nautical radar image sequences [1].

SEPARATION OF THE SPECTRAL NOISE

An algorithm to separate the wave induced signal from the background noise was developed for the use of nautical radar image sequences.According to the linear theory of gravity waves the wavenumber vector $\vec{k}$ and the frequency ω are related by the dispersion relation

$$\omega = \sqrt{g\, k \tanh(k\, h)} + \vec{k} \cdot \vec{u}, \quad (5)$$

where g denotes the earth's acceleration, h the water depth and $\vec{u}$ the velocity of encounter. The dispersion relation forms a shell in the frequency-wavenumber space [5]. Therefore the spectral variance of the image spectra due to the modulation of of the surface gravity waves is located in vicinity to thje dispersion shell. This dispersion shell is used as a filter to separate the spectral wave energy from the background noise. The total variance of the spectral background noise is compared with wind measurements.

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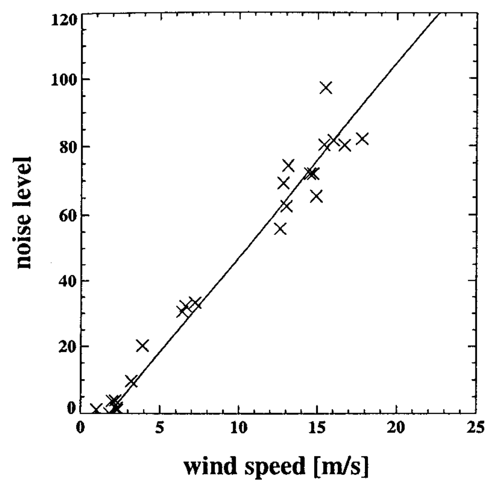

Fig. 1. The dependence of the spectral noise on the wind speed for azimuth angles from 170° to 180° (upwind).The slope of the regression line is a measure for the for the variance of the background noise.

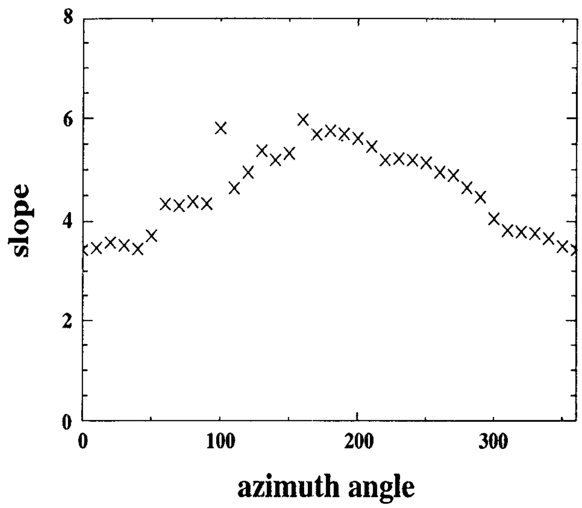

Fig. 2. Azimuthal dependency of the spectral noise shown by the slope of the regression lines of the angle classes.

AZIMUTHAL DEPENDENCY

The azimuth is defined here as the angle between the antenna look direction and the wind direction, with 180° looking upwind and 0° looking downwind. The azimuthal dependency of the spectral noise was analysed with a data set acquired during a cruise with the German research vessel 'Gauss' in the Norwegian Sea in fall 1995. A nautical radar with horizontal polarisation (HH) was used. More than 1800 Cartesian radar image sequences of 32 images has been analysed. The Cartesian images cover a 90° azimuthal section. Thus the full 360° azimuthal dependency can not be obtained by a single image sequency. The data set was splitted into 36 angle classes of 10 degrees and ordered into one of these classes by parallel measurements taken by a wind vane. The dependence of the spectral noise E_n on the wind speed V_W is determined for every angle class. An example is given in Fig.1 for measurements with the class of 170° to 180° (upwind). The wind speed dependency is approximated with a straight line

$$\sum_{\vec{k},\omega} E_n(\vec{k},\omega) = a + b \cdot V. \qquad (6)$$

The coefficients a and b are obtained by a linear regression. Within the range of the investigated wind speeds up to 23 m/s, no saturation is visible (Fig.1). Further, the lower limit of this measuring system becomes evident, because at a threshold of wind speed less than 2 m/s the roughness of the sea surface is too small to cause a measurable backscatter. With the slope of the regression line b the azimuthal dependency of the spectral noise is shown. In Fig.2 the slopes for the angle classes are plotted. The slope and therefore the background noise has a maximum for upwind and a minimum for downwind.

The azimuthal dependency of the radar backscatter has been analysed with radar data taken in the Odra lagoon in summer 1997. Here data sets of polar images of 360 degrees were available. The azimuthal dependency of the radar backscatter has been analysed by integrating the grey levels of each radar beam. The result is shown in Fig.3. In analogy to the variance of the spectral noise only one maximum in upwind direction exists.

The C-band model CMOD_IFR2 is used to derive the NRCS of calibrated C-band radars with vertical polarisation at moderate incidence angles [6]. This model was used to compute the azimuthal dependency of the NRCS between 20° and 40° and for wind speeds of 10 m/s and 14 m/s (Fig.4). In opposition to the nautical radar analysis a second maximum in the downwind direction appears.

SUMMARY AND OUTLOOK

With a nautical radar operating at grazing incidence and with HH polarisation the azimuthal dependency (concerning the wind) of the background noise and the radar backscatter has been analysed. The maximum of backscatter is in the upwind direction. In comparision at moderate incidence angle and VV polarisation a second maximum appears in the downwind direction. This result indicates that different backscatter mechanisms are dominant. For

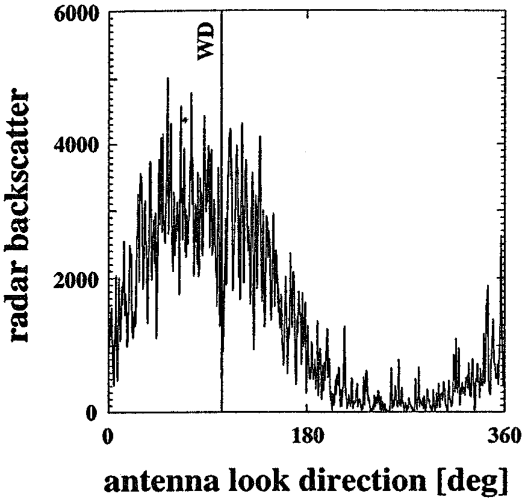

Fig. 3. Integrated grey levels of each radar beam as a measure of the backscatter against the direction of the beam. The wind direction (WD) is 106° and the wind speed is 9.3 m/s.

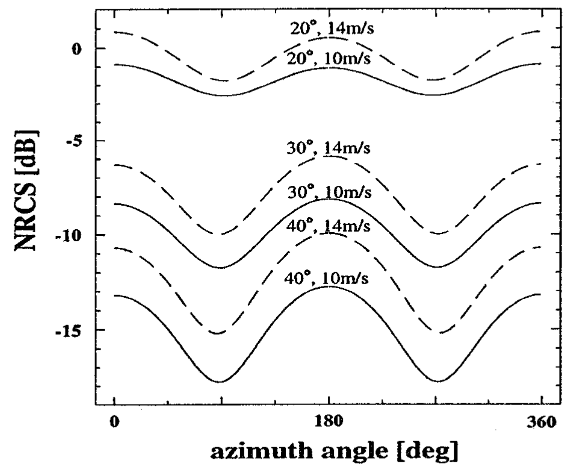

Fig. 4. The azimuthal dependency of the normalized radar cross section (NRCS) computed with the CMOD_IFR2. Solid lines represent wind speeds of 10 m/s and dashed lines of 14 m/s.

moderate incidence and VV polarisation Bragg waves are the main sources of backscatter, whereas at grazing incidence scattering on small scale breaking waves [7] contributes mainly to the radar return. A future task is the analysis of the azimuthal dependency of the spectral wave signal and the SNR in context to the calibration method. The dependence of the spectral noise on the wind speed indicates no saturation. A directional ambiguity does not occur for the nautical radar, because only one maximum in upwind direction exist. Therefore the nautical radar can be used as a wind sensor after a calibration with independent wind measurements.

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References

[1] F. Ziemer, An Instrument for the Survey of the Directionality of the Ocean Wave Field, Proceedings of the WMO/IOC Workshop on Operational Ocean Monitoring using Surface Based Radars, Geneva, Report No. 32, pp. 81-87, 1995.

[2] K.D. Ward, Compound Representation of High Resolution Sea Clutter, Electronics Letters, 17, 561-563, 1981.

[3] W. Alpers and K. Hasselmann, Spectral Signal to Clutter and Thermal Noise Properties of Ocean Wave Imaging Synthetic Aperture Radars, International Journal of Remote Sensing, Vol. 3, No. 4, pp. 423-446, 1982.

[4] W.J. Plant and L.M. Zurk, Dominant wave directions and significant wave heights from synthetic aperture radar imagery of the ocean, Journal of Geophysical Research, Vol. 102, No. C2, pp. 3473-3482, 1997.

[5] J. Seemann, F. Ziemer and C.M. Senet, A Method for Computing Calibrated Ocean Wave Spectra from Measurements with a Nautical X-Band Radar, Oceans'97 Conference Proceedings, Halifax (Canada) 6-9 October 1997, Vol. 2, pp 1148-1154.

[6] Y. Quilfen and A. Bentamy, Calibration / Validation of ERS-1 Scatterometer Precision Products, Proc. of IGARSS 1994, Pasadena, United States, pp. 945-947, 1994.

[7] D.B. Trizna, A Model for Brewster Angle Effects on Sea Surface Illumination for Sea Scatter Studies, *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 35, No. 5, pp. 1232-1244, 1997.