Wave and Wind Parameters from HF Ocean Radar

Mal L. Heron, Jasmine B. D. Jaffrés
Australian Coastal Ocean Radar Network, Marine Geophysics Laboratory,
James Cook University, Townsville, QLD 4811

Andrew Middleditch
Seaview Sensing Ltd, Sheffield Technology Parks, Arundel Street, Sheffield S1 2NS, UK

Introduction

A sparse network of surface current and wave-capable HF radars is being established around the Australian coastline to produce quality controlled data into a public-domain archive under the umbrella of the Integrated Marine Observing System (IMOS). The phased array installations within the Australian Coastal Ocean Radar Network (ACORN) produce maps of significant wave heights, and wind directions, and under good signal-to-noise conditions, generate directional wave spectra.

The radar installations are always made in matched pairs, spatially separated so that the beams formed by the phased arrays cross at a non-acute angle in the primary area being mapped; this gives the 2-D capability of each radar pair. Phased-array stations are installed at the Capricorn/Bunker Groups, QLD (Tannum Sands, and Lady Elliot Island); the entrance to the South Australian Gulfs, SA (Cape Wiles, Eyre Peninsula and Cape Spencer, Yorke Peninsula); Rottnest Area, WA (Port Beach, Fremantle and Guilderton); and Coffs Harbour, NSW (Red Rock and North Nambucca).

Extraction of wave and wind parameters from HF radar

In order to make proper use of the data from HF radar, it is important to understand the methodology, the algorithms, and the limitations. This is a remote sensing method where the basic data are time series of radar echoes from a patch of ocean defined by the propagation time of the electromagnetic wave from the transmitter to the patch and back to the receiver, and the width of the beam formed by the phased-array. A power spectrum of the echoes from such a patch of ocean is shown in Fig. 1. The frequency range on the abscissa is ±1 Hz, which represents the Doppler shifts imposed by the dynamic sea surface. The dominant peaks near ± 0.298 Hz are the Bragg peaks for a radar frequency 8.5125 MHz. Essentially all other energy above the base noise level (near ± 1Hz) is due to second-order scatter from non-linear properties of the waves, or from double scatter of the electromagnetic wave. It is the double scatter which gives us information about the wave heights and the directional wave spectrum.

The two Bragg peaks (A and B) are from waves with the resonant wavelength which are propagating towards and away from the radar site. The frequency offset from the calculated position (dashed line) is proportional to the surface current component in the radial direction away from the radar station.

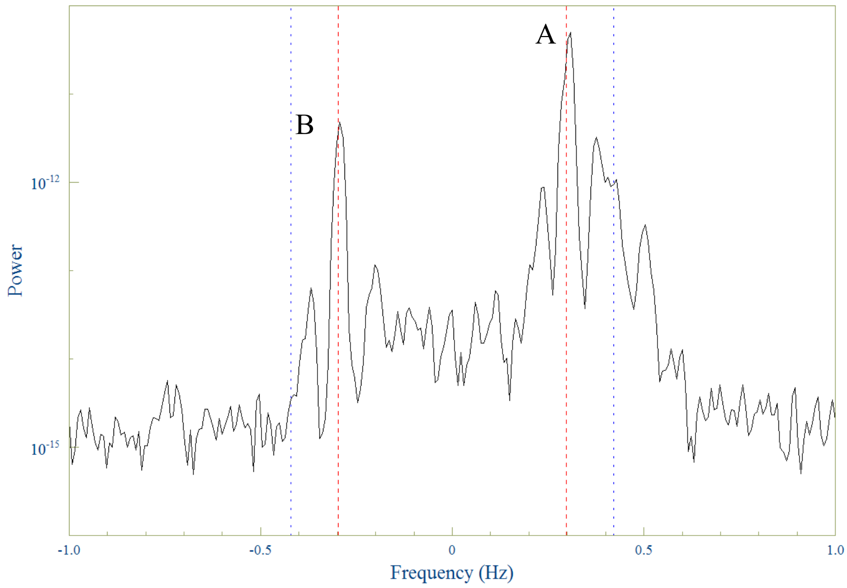

Fig. 1 Doppler spectrum of echoes from a defined patch of ocean. The dominant peaks, A and B, are from first-order Bragg scatter, and the surrounding energy is from second-order scatter due to hydrodynamical effects in the gravity waves, and a double-scatter effect.

Wind direction

The wind direction is determined from the relative energy in the two first-order Bragg lines. Because it is solely based on the first-order energy, wind directions (and surface currents) are available from the maximum working range of the radar at any time. The extraction of wind direction assumes a directional spreading function for the gravity waves at the Bragg wavelength. For a radar operating at 8.5125 MHz the Bragg wavelength is 17.62m, which is a short wind wave. We adopt the model of Longuet-Higgins et al. (1963) and assume the spreading function is

$$G(k,\theta) = A(k)\cos^{2S}(\theta - \theta_0) \tag{1}$$

where θ_0 is the wind direction, k is the wavenumber of the gravity wave, S is a spreading parameter, and $A(k)$ is a normalizing factor such that

$$\int_0^{2\pi} G(k,\theta) = 1. \tag{2}$$

In the routine algorithm for wind direction, we use equations (1) and (2) with S = 2, and the measured ratio, R, of the energy in the first-order Bragg peaks. Then, following Heron and Prytz, (2002):

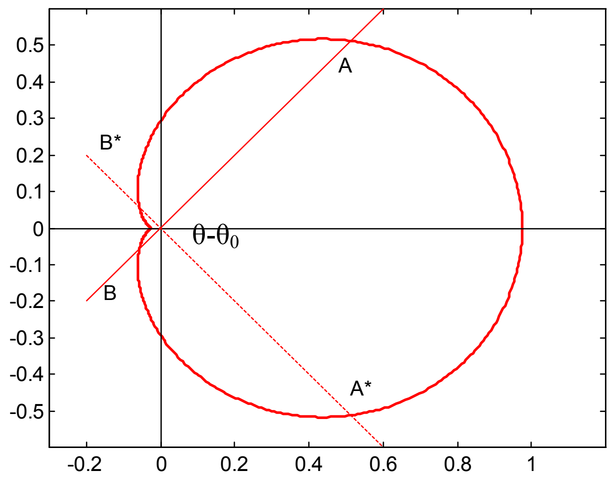

Fig. 2 The algorithm model for wind direction. A given ratio, R, has two solutions, A/B, and A*/B*.

$$|\theta - \theta_0| = \left| 2\arctan\left(R^{1/2S} \right) \right| \quad . \tag{3}$$

There is an ambiguity between $\pm(\theta\text{-}\theta_0)$ which is resolved by using the same analysis procedure for the other station.

Significant wave height

Barrick (1977) derived a relationship for rms wave height as:

$$h_{rms}^2 = \frac{2\alpha^2 \int_{-\infty}^{+\infty} [\sigma_2(\omega_d) W(f_d)] df_d}{k_0^2 \int_{-\infty}^{+\infty} \sigma_1(f_d) df_d} \tag{4}$$

where f_d is the Doppler frequency, σ_1 and σ_2 are the first and second-order scattering cross sections respectively, k_0 is the radar wavenumber, and $W(f_d)$ is a weighting function which removes cusps in σ_2. The coefficient α is a scaling factor. Barrick noted the theoretical limitation which requires $k_0 h_s < 0.6$, where h_s is the significant wave height, because of the truncation of second-order expansions. Heron and Heron (1998) evaluated the empirical coefficients by comparing HF radar output with a wave gauge, and suggested $\alpha = 2.20$. They also pointed out that this algorithm is not reliable when the radar beam is within about 15 degrees of orthogonal to the wind direction. An improved algorithm is being developed to account for inaccuracies as the angle changes between the wind direction and the radar beam; and to account for higher-order expansion for high wave heights which breach the theoretical limitation suggested by Barrick (1977).

Directional wave spectra

$$\sigma_2(\omega) = 2^6 \pi k_0^4 \sum_{m,m'=\pm1} \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} |\Gamma|^2 S(m\tilde{k}) S(m'\tilde{k}') \delta(\omega - m\sqrt{gk} - m'\sqrt{gk'}) dp dq \qquad (5)$$

The expansion for the second-order scattering cross-section, σ_2 in equation (4) involves a double integral of $S(\tilde{k})S(\tilde{k}')$ (equation (5)) over wave- number space, where

$$\tilde{k} + \tilde{k}' = -2\tilde{k}_0 \qquad (6)$$

is required to satisfy the Bragg criterion for double scatter. Wyatt (1990) has developed an inversion which fits a Pierson-Moskowitz model for the wind waves, makes simplifying assumptions to reduce the kernel of the integral, and iteratively solves for the directional spectrum of the longer waves.

Acknowledgments

This work is supported by an Industry Linkage grant from the Australian Research Council in collaboration with Seaview Sensing Ltd (UK) and Helzel Messtechnik GmbH (Germany). Data were sourced from the Integrated Marine Observing System (IMOS), under the National Collaborative Research Infrastructure Strategy (NCRIS).

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