URSI GASS 2023, Sapporo, Japan, 19 – 26 August 2023

Ocean Surface Wave Parameter Estimation using Periodogram Method

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Abstract

The Doppler spectra of received data from HF radars from the ocean surface have always been an important part of ocean parameter estimation for many decades [1]. Determining the Doppler spectrum from the received time series data, and then processing it, leads to the extraction of important wave parameters, such as significant wave height, peak wave period, and principal wave direction. However, following the work in [2], [3], finding the Doppler spectrum can be bypassed using other methods. In this paper, we use Welch's Periodogram approach to retrieve the ocean surface significant wave height and the peak wave period. Using this method simplifies the processing of the received electric field backscattered from the ocean surface.

1 Introduction

Following the work of Gill [4] and Walsh and Gill [5], the authors determine the power spectral density per unit area of a radar in a general bistatic configuration of Figure 1, by finding the auto-correlation $\mathscr{R}_{11}(\tau)$ of the received electric field and then taking its Fourier Transform.

$$\mathscr{R}_{11}(\tau) = \frac{\lambda_0^2 G_r}{8\pi^2}\left\langle \left(E_{0_n}^{+}\right)_{11}(t_0, t+\tau)\left(E_{0_n}^{+}\right)_{11}^{*}(t_0, t)\right\rangle \quad (1)$$

$$\mathscr{P}_{11}(\omega) = \mathscr{F}\{\mathscr{R}_{11}(\tau)\}, \quad (2)$$

where $E_{0_n}^{+}$ is the received first-order electric field in time domain t, $\mathscr{P}_{11}(\cdot)$ is the Doppler power spectral density, λ_0 is the free space wavelength of the transmitted signal, G_r is free space gain of the receiving antenna, and t_0 and τ are a stationary time for a patch and the time shift, respectively. However, to bypass the extraction of the Doppler spectrum, in [2] the relation between the first-order received electric field and the ocean height for a restricted monostatic configuration is derived as

$$\left(E_{0_n}^{+}\right)_1(\tau) \approx \mathscr{F}^{-1}\left[-\frac{j\omega C_0}{(2\pi)^2}\right] * \int_\theta \frac{F^2(\rho)}{\tau}\frac{\partial \xi(x_1, y_1, t)}{\partial \rho} d\theta \quad (3)$$

where $\mathscr{F}^{-1}$ is the inverse Fourier transform, $*$ is the 2-D convolution operator, $\xi(x,y)$ is the surface height of the ocean at position (x,y) (see Figure 2), which may be written in the form of a two-dimensional Fourier series [5], the

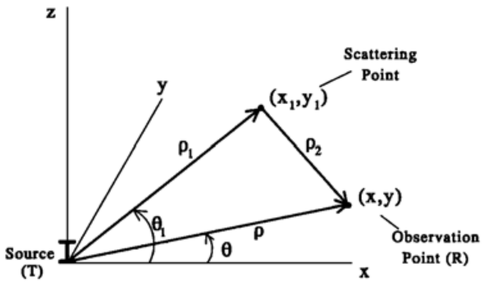

Figure 1. Geometry of the first-order scatter [5]

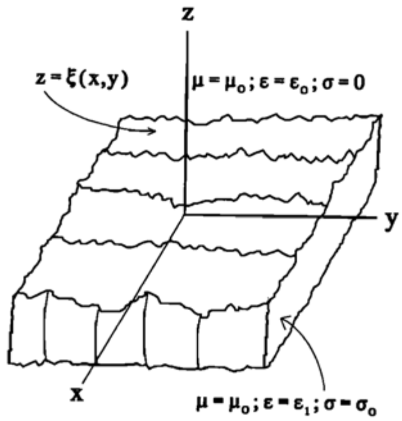

Figure 2. Geometry of the first-order scatter [5]

$F(.)$ is Sommerfeld attenuation function [7], ω is the angular frequency of the radar, ρ is the scattering patch distance to the transmitter and θ is the direction of the ρ. Also, within Equation (3), C_0 is defined as:

$$C_0 = \frac{\Delta\ell I k_0^2}{j\omega\varepsilon_0}.$$

where $\Delta\ell$ is the length of dipole, I is current, k_0 is the radar wavenumber and ε_0 is free space permittivity. After matched filtering and using the Divergence Theorem and the fact that ρ and τ are constant along the scattering circle [2]

$$\left(E_{0_n}^{+}\right)_1(t) \approx M_2 \int_{x_1}\int_{y_1} \xi(x_1, y_1, t)\, dy_1 dx_1 \quad (4)$$

where $M_2 = \left(4k_0^2 F^2(\rho)\right)/(\tau)M_1$ and M_1 is some constant. Restricting our attention to a single-ocean patch, we obtain

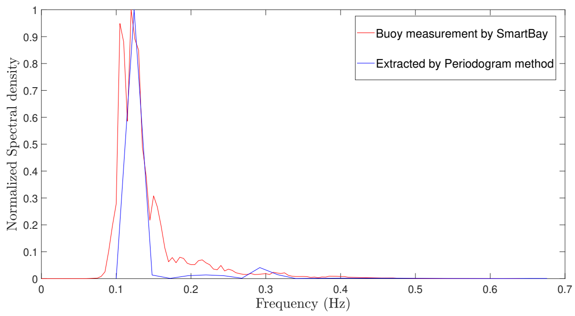

Figure 3. Spectral density of the ocean patch

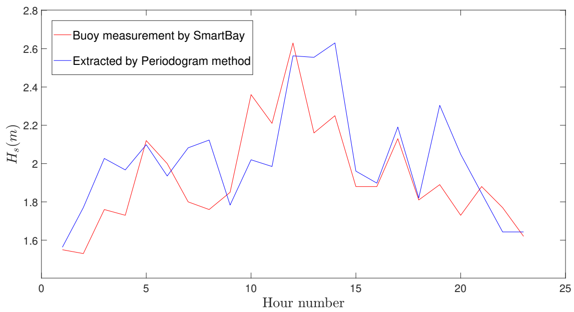

Figure 4. Significant wave height vs hour number

$$\left(E_{0_n}^{+}\right)_1 (x_1, y_1, t) \approx M\xi\,(x_1, y_1, t) \tag{5}$$

where, M is some constant [2]. Equation (5) shows that the received first-order electrical field from any general ocean patch is linearly proportional to the mean wave height on that patch.

Here, we use Welch's Periodogram approach [6] which will simplify our processing. By taking the periodogram of both sides in (5), proportionality of the desired ocean wave spectrum to the spectrum of the first-order electric field is determined. Our intention is to retrieve the significant wave height (H_s) and peak wave period (T_p) using the Welch method.

In this paper, to test and verify the proposed periodogram approach, field data collected by a WERA system transmitting at a center frequency of 13.385 MHz are used. Also a wave buoy concurrently made ocean measurements in parallel, with data provided by SmartBay [8]. Both radar and buoy-measurements were made near Red Island, Placentia, Canada.

Figure 3 shows a comparison of the spectral density of the ocean extracted from the periodogram method with the buoy-measured data on site. The achieved spectral values should be calibrated with the ground truth buoy data. This graph validates the functionality of the Welch's approach

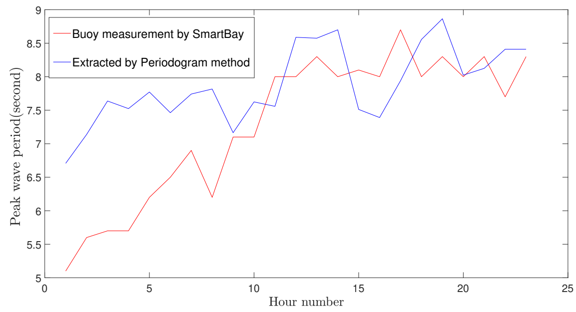

Figure 5. Peak wave period vs hour number

for a determined ocean patch in an specific time period of 1 hour. Therefore, we would be able to extract the wave spectra without calculating the Doppler spectrum, but instead using the received time series from the HF radar. As explained above, the objective is to obtain the wave parameters. Figures 4 and 5 present results from the significant wave height estimation and the peak wave period using the periodogram method, respectively. As shown on the horizontal axis, we have considered 24 hours of data to verify the reliability of our method. It is required that the extracted data be calibrated with the buoy measurement data provided by SmartBay.

2 Conclusion

In the conference presentation, the statistical parameters of the ocean surface such as significant wave height and the peak wave period for a long period of time will be verified and will be presented.

Acknowledgements

The authors would like to acknowledge the support of NSERC with Grants RGPIN-2020-07155 and RGPIN 2020-05003. The first author also would like to thank Dr. Reza Shahidi and Prof. Eric Gill for their helpful comments on the earlier draft of this manuscript.

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