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Volatility Modeling for Ocean Significant Wave Height Estimation

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***Abstract*—In a previous paper by the same authors in the current conference series [1], an interesting relation was derived which showed that the significant wave height H_s is linearly proportional to the standard deviation of the received time series from a monostatic HF radar. In the current paper we use this relation along with methods from the field of volatility modeling, which is often used in financial mathematics, to provide accurate estimates of significant wave height. We demonstrate on field data from Argentia, Newfoundland, Canada that the use of such methods gives slightly more accurate H_s estimates than using a simple windowed variance calculation.**

***Index Terms*—HF radar, ocean wave parameter estimation, volatility modeling**

I. Introduction

Ocean wave parameter estimation from HF radar data has traditionally been performed by first forming the Doppler spectrum from the received data, and then performing further processing on this spectrum to extract desired ocean wave parameters such as significant wave height (H_s) and principal wave direction. In our paper from an earlier instance of this conference [1], we introduced a paradigm shift where instead of following the traditional methodology of first forming the Doppler spectrum, we dealt directly with the received time-domain data from the HF radar. This work was further developed by the authors in [2].

From an equation modeling the first-order return from a pulsed HF radar, we found that the significant wave height is linearly proportional to the standard deviation of either the real part, the imaginary part of the magnitude of the received voltages from the HF radar. Furthermore, the proportionality constant was found to theoretically not depend on the ocean patch under consideration, meaning that once it was found in one patch, the same constant could be used in another.

In the field of financial mathematics, volatility analysis is a common tool to, for example, estimate the volatility of time series from stock markets, which might itself be time-dependent. Such tools are based on well-founded and developed statistical estimation theory. One component of such volatility estimation is the determination of the variance of the time series data at any given time. By virtue of the previously-derived linear proportionality relationship between the standard deviation (square root of the variance) of the received HF radar time series and the significant wave height of the interrogated ocean wave field, this suggests the application of such volatility analysis to the received HF radar time series as a way of estimating time-dependent significant wave height values.

In this paper, we apply a typical model for volatility analysis on field data acquired from our group's Wera HF radar installation at Argentia, Newfoundland, Canada and find that we obtain slightly better results in terms of root-mean squared error (RMSE) for the significant wave height than those found in [1]. Perhaps more importantly, we have now initiated the use of the vast framework of volatility estimation to the problem of significant wave height estimation, which could enable further positive developments in the latter.

II. Volatility models

Volatility models have been a tool for estimation of, for example, financial markets. Two commonly-used volatility models are autoregressive conditional heteroskedasticity (ARCH) and generalized autoregressive conditional heteroskedasticity (GARCH) models. GARCH models assume an autoregressive moving average (ARMA) model for the error variance. In this paper, the main work in volatility estimation is performed according to the MIDAS Hyperbolic ARCH model. We do not include the mathematical details of the model here. The reader may refer to [3] for such details.

We used a zig-zag estimation strategy where first a fixed variance was estimated using a Heterogeneous Autoregression with exogenous regressors (HARX) model, and then the esimates from this model fed into a MIDAS Hyperbolic ARCH model. This was done for 10 iterations for each data segment. More details will be provided in the presentation at the conference.

III. Results

The ARCH toolbox written in Python [4] was used to obtain the results in this paper. The MIDAS Hyperbolic ARCH model was used to estimate variances with a maximum lag of 512

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samples. This was quite a large lag but led to improved results over smaller maximum lag values.

The radar data was acquired by a Wera HF radar system in Argentia, Newfoundland, Canada in July of 2018. For the purposes of this paper, we used a 2-week segment of the data from July 4 to July 17 inclusive to test the proposed method. At the same time that the radar data was recorded, wave parameter data was obtained from a wave buoy in the region covered by the radar. The real and imaginary parts of the radar data were each smoothed with a sliding average window of length 3 samples. In the data, the sampling time is roughly 0.39 s. Then the MIDAS Hyperbolic ARCH model was applied to extract variances from both the real and imaginary parts. Finally, the result was once again smoothed, this time with a median filter of length 6, and the estimated variances from each of the real and imaginary parts averaged with each other to form the final estimate of the variance at each sample time. Finally, the estimated variances were averaged over the entire hour to obtain the estimated variance for the hour, after which the square root was taken to find the estimated standard deviation. Then using the fact that the standard deviation of each time series is roughly linearly proportional to the significant wave height, linear least squares was used to estimate the proportionality constant with respect to the recorded wave buoy data. Finally, this estimated proportionality constant was used to obtain the corresponding H_s values for each hour of the radar data.

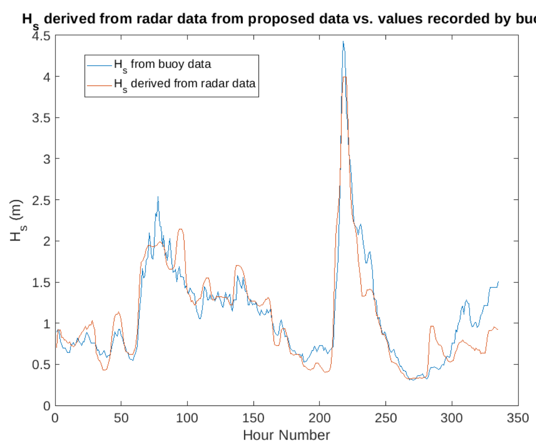

Fig. 1. H_s derived from radar data using proposed method vs. values recorded by wave buoy

These H_s values derived from the radar data are plotted against the wave buoy values in Figure 1. It was found that the root-mean squared error (RMSE) was roughly 24.40 cm and the correlation coefficient was roughly 0.893. These values are similar to those found in [2] where the same dataset was used for testing. There, the RMSE was found to be 25.40 cm and the correlation coefficient was found to be 0.926. The advantage of the current work is that there is more flexibility in using different volatility estimation methods with different parameters and, with more testing, it is possible that even better results might be obtained.

IV. Conclusions

In this paper, for the first time in the literature, volatility models from financial mathematics were applied to the problem of significant wave height estimation in the ocean from HF radar data. Good results were obtained from a preliminary application of such methods, and it is expected that through further testing, these promising results could be further improved. These estimates of significant wave height can be used for example to constrain the inversion process for wave spectrum extraction from HF radar data as is done in [5].

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