Hydrodynamics of the Alderney Race: HF Radar Wave Measurements

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***Abstract*-** In this contribution we present the first wave measurements collected with a HF radar installed at the north-west coast of France to overlook a promising area for tidal energy extraction. The radar measurements are aimed to help understanding the oceanographic conditions at the site, aid the validation and improvement of numerical models, and ultimately the calculation of tidal stream energy. The results show good agreement when compared against ADCP measurements, especially when the current speed is below 1 m s^{-1}. The latter appears to have a clear influence not only on the quality of the radar's wave results, but also on their spatial extent.

***Keywords*-** HF radar, Alderney Race, sea state, surface current, tidal energy.

I. INTRODUCTION

For the design of effective and profitable tidal farms, capable of providing a quality service to end users, an accurate estimation of the available resource is of paramount importance. However, these estimates are presently subjected to errors of about 10%, which can in turn lead to deviations of 30% on the calculated tidal stream energy [1]. An important part of this error arises from neglecting wave-current interactions and three-dimensional effects in the numerical simulations performed to estimate the resource. This practice is partly related to the lack of data against which to validate the results; a situation derived from the difficulties associated to the direct measurement of oceanographic data in the highly energetic areas where most tidal deployments are planned.

The Alderney Race is a strait located between the north-west coast of France and the Island of Alderney (UK) that has been targeted as a promising area for hosting tidal energy converters. Moreover, it also constitutes one of the locations where the long term collection of in situ measurements poses a particular challenge. The circulation of the area is characterized by strong tidal currents that accelerate when constricted between the French coast and the Channel Islands. Furthermore, the region is subjected to strong winds that create an energetic wind wave climate, which combined with the swell waves arriving from the Atlantic, results in a complex wave field. The combination of such wind, current, and wave fields, together with a complex bathymetry, makes of the area a very hostile environment for navigation, as well as for the deployment of in situ measuring devices. Therefore, long term records on the area are scarce.

Overcoming this scantiness of long term measurements is one of the main objectives of the HYD2M project, which aims to collect a comprehensive dataset that can help understanding the hydrodynamic processes of the Alderney Race, as well as the effects of their interactions. To this end, a pair of HF radars has been recently deployed to monitor the waves and surface currents over the strait. These devices transmit an electromagnetic (EM) signal at a frequency within the HF band, and record the backscatter that results from its interaction with the sea surface. Spectral analysis of this backscatter results in what is known as the Doppler spectrum, which is characterized by two prominent peaks resulting from the coherent backscatter of the EM signal off first-order linear waves of half the transmitted wavelength, travelling toward or away the radar stations. The position of these peaks, known as first-order or Bragg peaks, allows resolving for the speed of the current, as well as its direction if the data from the two radars are combined. In addition, higher order waves with half the radio wavelength may also contribute to the measured signal, appearing on the sides of the first-order peaks mentioned above. This part of the spectrum, commonly referred to as the second-order energy, can be used to retrieve the directional spectrum of waves (e.g. [2], [3], [4]) or some of its summary parameters (e.g. [5], [6], [7]).

Since they are deployed at the coastline, HF radars are not directly subjected to the marine conditions in the same way in situ devices are, and this constitutes a clear advantage in an environment such as the Alderney Race. Nonetheless, under certain oceanographic conditions, challenges to the technique might still arise. For example, the width of the first order peaks of the Doppler spectrum broadens if the current varies during the measuring period [8], or if there is a non uniform current within a radar target cell [9]. Furthermore, in the presence of shear, or during energetic sea states, the 1st and 2nd order areas of the Doppler spectrum used to calculate the surface current and the wave spectrum, respectively, can convolve. This situation, which is expected to severely affect our measurements, complicates the discrimination between the two above-mentioned spectral areas, compromising the results, especially the wave spectrum estimates.

This study shows the first wave results derived from the measurements of the Alderney Race HF radar. By comparing the results against in situ measurements, we expect to identify the factors affecting their quality to be able to design specific treatments for their improvement.

The paper is organised as follows. In the next section we describe the study site and the data used here. In section III we summarise the methods used to process the data. In section IV we present the results, and in section IV we summarise the findings and future directions of work.

II. STUDY SITE AND INSTRUMENTATION

The measurements analyzed in this work were collected over an area covering the Alderney Race; a strait located between the northwest coast of France and the Island of Alderney (UK). On this region, the wave climate is a combination of locally generated wind waves, and the long period swell that propagates across the North Atlantic, which are both modified by a current field dominated by tidal streams exceeding the 3 m s^{-1}. With a tidal range around 6 m, water depths between 30-60 m, and the high current speed resulting from the acceleration of the tidal flow between Cap de La Hague and the Channel Islands, this area constitutes a promising area for the extraction of tidal energy [10].

As part of HYD2M project, two WERA phased-array radars [11] have been installed in the area to monitor the surface current and the waves of the area. The stations are located at Jobourg and Goury, approximately 5 km apart (Figure 1). Each site has a 16-element receiving array, and two square 4-element transmitting arrays, which operate at 13.5 MHz and 24.5 MHz, respectively. With this arrangement, it is possible to asynchronously operate the radars at the two different frequencies, given the shared receiving array. The dataset used for this work was collected between 24 and 25 January 2018, when the two radar stations were simultaneously operational. After this date, a technical problem arose at the radar station at Goury, which hinders the quality of the results. Furthermore, although the results can be calculated with the two radars operating at different frequencies, we chose to use only the fraction when this was not the case, and therefore excluded the first hours of 25 January. During the period of common operation, both radars transmitted at 13.5 MHz, acquiring measurements for 17 min 45 s at approximately 1.5 km range resolution and 11 deg. azimuthal resolution. These data were then set into a uniform grid at 500 m resolution.

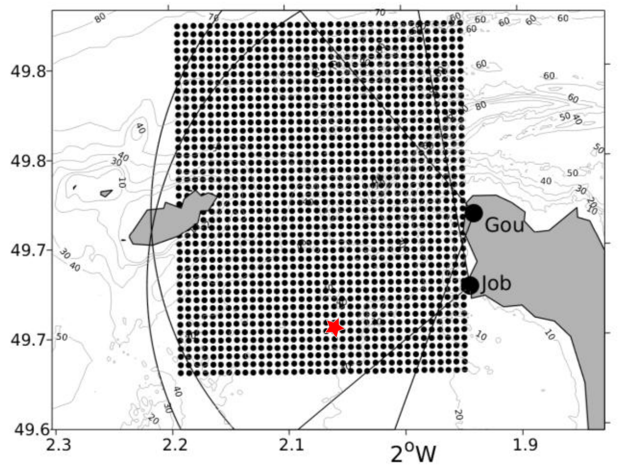

Figure 1 : Map showing the radar stations at Goury (Gou), and Jobourg (Job), their maximum coverage for wave measurement (black arcs), and measuring grid (black dots). The red star indicates the position where the ADCP was deployed. The latitude is degrees North, and the longitude degrees West.

The in situ dataset used to compare the radar data against was collected using an ADCP Teledyne RDI Sentinel V50 that was deployed within the radar's field of view from 15 October 2017 to 24 February 2018. The ADCP operated at 600 kHz, acquiring measurements for 20 min, every hour, at 2 Hz.

III. METHODS

Radar directional ocean wave spectra were derived from the recorded backscatter using the Seaview algorithm [2], which solves the equations that describe the second-order scatter from ocean waves [12]. The result is a wave number directional spectrum with a variable amount of wave numbers, and 30 directions at 12º resolution. This was subsequently converted into the directional frequency spectra using the wave dispersion relation.

The ADCP orbital velocities were processed into directional spectra using RDI's Wavesmon software. The iterative maximum likelihood method (IMLM; [13]) was applied to compute directional spectra at 0.0156 Hz frequency resolution, and 90 directions at 5º resolution.

IV. RESULTS AND DISCUSSION

Given the short period of data available for this work no statistical indicators were calculated, as they would lack significance. Therefore, we base our analysis on the direct comparison between wave spectra derived from the measurements of the radar and the ADCP.

The dataset presented here covers the two ends of one tidal cycle characterized by a tidal range of about 4 m, and a surface current that reached the 2 m s^{-1} one hour after high tide. Over this period the wind was blowing from the south-west, with speeds between 8 and 10 m s^{-1} (Figure 2).

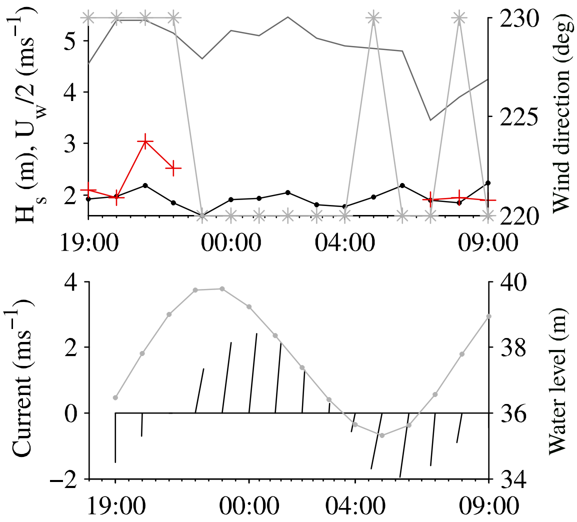

Figure 2: The top panel shows the significant wave height measured by the ADCP (black line and dots), and by the radar (red line and cross). The 10 m wind speed (grey line) and direction (grey and star), measured at a meteorological station at Goury are also shown. The lower panel shows the water level as measured by the ADCP (grey line and dots), and the current vectors measured by the radars (black lines).

Wave directional spectra and derived 1D spectra measured by the two devices are shown in Figures 4 and 3, respectively. In general, and with the exception of the results obtained at 08:00 on 25 January, the distribution of energy over frequencies on the spectra derived from the two devices matches one another (Figure 3).

The first two measurements, collected just before slack tide, at 19:00 (not shown) and 20:00 (Figure 3a), show radar spectra that are accurate both in shape and energy content. This is translated into wave height differences of 16 and 3 cm, respectively. The directional spectra measured at 20:00 are plotted in Figures 4a and 4b. Both spectra show two modes, around 0.09 Hz and 0.14-0.15 Hz. However, the radar contours are broader, and the direction of arrival of the low frequency wave field is from the north-west, while that of the ADCP comes from the west. Two hours later, at high tide, the radar overestimates the energy density, showing a difference of about 2 m^2 at the spectral peak compared to the ADCP. Similarly to the previous case, the directional spectrum (Figure 4c) is broader than that of the ADCP (Figure 4d), and the direction of arrival is shifted towards the north. The morning after, the directional spectra obtained with the two devices (Figures 4e and 4f) show three wave modes below 0.15 Hz. However, while the higher frequency mode of the radar extends up to 0.2 Hz, the ADCP shows a differentiated wave field peaked at about 0.16 Hz frequency, which can be clearly seen at the one-dimensional spectra (Figure 3c). Finally, 4 hours after low tide on 25 January, the energy density measured by the radar at the peak of the spectrum (0.08 Hz) is 2.5 m^2 lower than that of the ADCP (Figure 3d). Once again, the directional spectrum (Figure 4g) shows broader contours and the energy density is substantially more spread over directions than it is seen on the ADCP spectrum (Figure 4h), which shows a very well defined swell coming from the west.

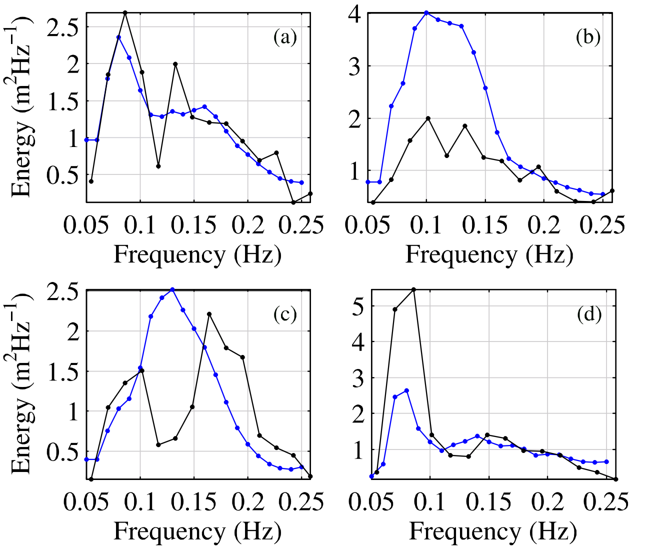

Figure 3: Wave spectra measured by the ADCP (black) and the radar at four different times through a tidal cycle. (a) 24 January 2018 at 20:00, (b) 24 January 2018 at 22:00, (c) 25 January 2018 at 08:00, (d) 25 January 2018 at 09:00. Note the different resolution of the two types of spectra: 0.015 Hz (ADCP), 0.01 Hz (radar).

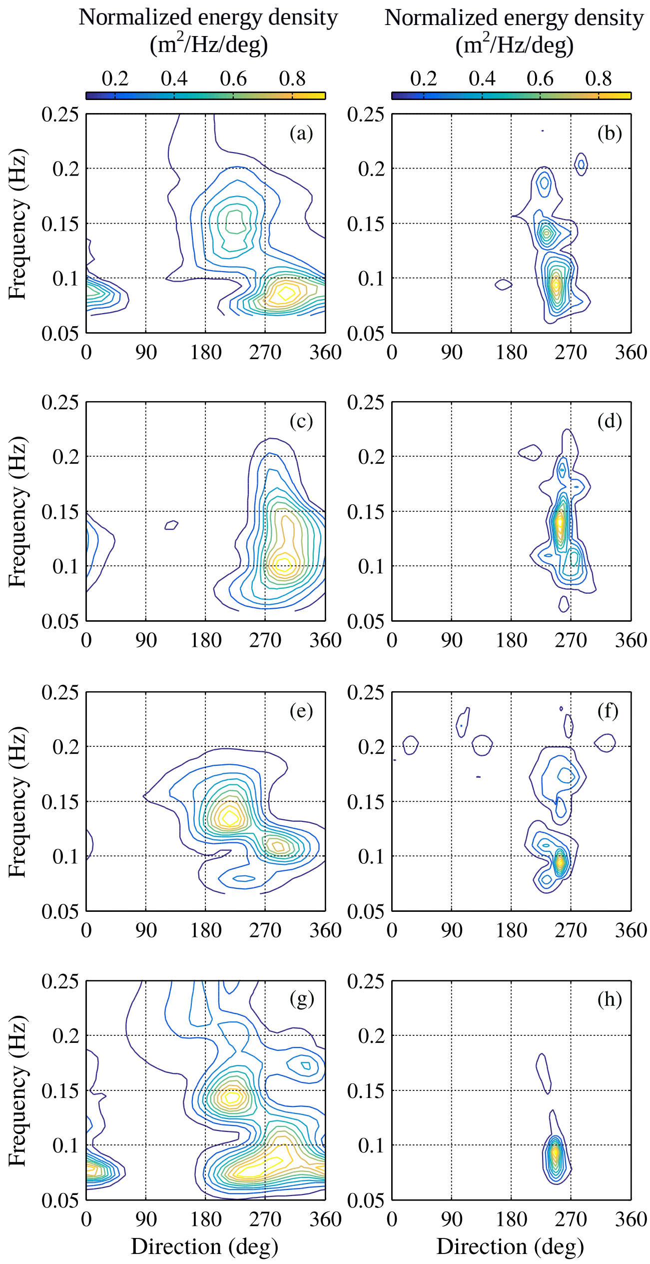

Figure 4: Wave directional spectra measured by the radar (left) and the ADCP (right). (a, b) 24 January 2018 at 19:00, (c, d) 24 January 2018 at 22:00, (e, f) 25 January 2018 at 08:00, (g, h) 25 January 2018 at 09:00. The colour scale represents the energy density normalized by the maximum of the spectrum. The contours are plotted at levels between 0.1 and 0.9, every 0.1 m^2/Hz/deg.

Figure 5 depicts wave height maps obtained at the same times as the spectra shown in Figures 3 and 4. Comparing the results with the current velocity presented in Figure 2, it is possible to assume there is a relation between the current speed and the radar's spatial coverage, where wave measurements are available. At the times when the current speed was below 1 m s^{-1} (Figures 5a and 5b) only few grid cells had no inverted data, and the coverage extended through the whole strait. However, as the current speed increased to reach 1.38 m s^{-1} at the location of the ADCP by 22:00 on 24 January, the wave results were limited to the central area of the radar's field of view. A low spatial coverage is also observed in Figure 5c, when the maximum current speed reached the 2 m s^{-1}. Contrary to the previous case, the wave results were limited almost exclusively to the far ranges at the western side of the strait.

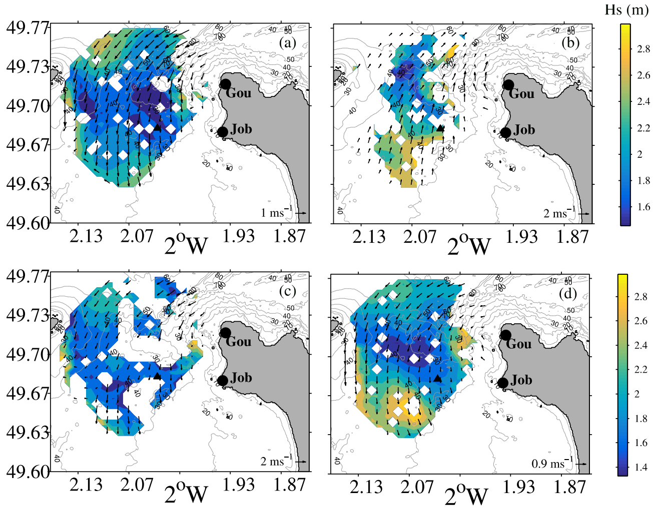

Figure 5. Maps of significant wave height (colour) and surface current (vectors) measured by the radar on (a) 24 January 2018 at 19:00, (b) 24 January 2018 at 22:00, (c) 25 January 2018 at 08:00, (d) 25 January 2018 at 09:00. The latitude is degrees North, and the longitude is degrees west. The colorbar indicates H_s in meters. The reference arrow represents the maximum current velocity measured.

V. CONCLUSION

The first measurements obtained with two WERA radars installed to monitor waves and surface currents at the Alderney Race have been presented. The results show well-shaped radar spectra, which are however broader than those measured by the ADCP. This has been previously observed in the results obtained with HF radar and the Seaview algorithm, and is generally attributed to the averaging and smoothing that is done during the inversion [13]. In addition, the low frequency wave fields measured by the radar have been found to be shifted towards the north with respect to the ADCP measurements. While the ADCP uses the orbital velocities at three different bins through the water column to derive the directional spectrum, HF radar measurements are based on the scatter off surface waves, and this might have an influence on the results. However, this is speculation and more data are required to confirm these observations. Finally, the results show a considerable variation on the radar's spatial coverage throughout the tidal cycle. Although the dataset is too short to draw any definitive conclusions, this appears to be related to the current speed, and is possibly associated to the mechanisms summarized on the introduction, and in [8] and [9], among others. However, additional analysis is necessary to better understand and quantify the effects of the current onto the radar wave results at our site, and further research will be focused on that.

ACKNOWLEDGMENT

This work is funded by ANR HYD2M (ANR-IO-IEED-0006-07), funded itself by the «Investissements d'Avenir» program. The HF radars were bought by Caen University in the framework of the «Manche 2021» project, co-funded by the EU and the Normandy county council, throughout the ERDF-ESF operational program 2014-2020

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