Advances in resource characterization in Alderney Race (English Channel)

Alexei Sentchev, Maxime Thiébaut, Lucille Furgerot, Pascal Bailly du Bois, and Mehdi Morillon

Abstract—**Tidal circulation and tidal stream resource in Alderney Race were assessed by using a towed acoustic Doppler current profiler (ADCP) system in conjunction with tidal modeling. Optimal Interpolation (OI) was applied to process the underway velocity measurements recorded at neap tide flood and ebb flow. The method employs velocity covariances derived from numerical simulations by a 2D model MARS. The interpolation technique allows to obtain the most likely evolution of the velocity field under the constraints provided by the ADCP observations. OI helps to identify zones (or time intervals) where the model fails in simulating the tidal flow and then corrects the model trajectory. The largest overall difference (~0.5 m/s) between the interpolated and simulated velocities was found on ebb tide in a broad area located 5 km off the French coast. The optimally interpolated velocity fields were used for assessing the tidal stream resource at site. Model post simulations constrained by velocity measurements demonstrated a significant (up to 30%) decrease of power available in the flow. It was shown that by merging high resolution underway velocity measurements at tidal energy sites with modeling, the tidal stream potential estimation becomes more accurate.**

Keywords— **ADCP measurements, Alderney Race, Optimal Interpolation, Tidal stream resource.**

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I. Introduction

In recent years, tidal stream energy has been growing rapidly in interest as countries look for ways to generate electricity without relying on fossil fuels. In comparison to other sources of renewable energy, tidal stream energy is accurately predictable and the social acceptance level is higher due to a reduced visual impact. For high efficiency and commercial viability of projects, the tidal energy convertors (TEC) require large current velocities: typically spring tide velocities in excess of 2.5 m/s [1]. Areas with such flow conditions have limited size and are located in general close to the shore: in straits, passages between islands, or in vicinity of headlands. The Channel Isles region possesses several of such areas [2]. Alderney Race, located North-West of the Cotentin Peninsula in France, is assumed to have the largest potential. This is relatively shallow water strait, 15 km large, with current velocities attaining 5 m/s due to flow amplification by topography [2], [3].

During the last two years, the hydrodynamics in Alderney Race was extensively assessed by combing modelling, *in situ* and underway measurements of flow velocity, and also surface current remotely sensed by High Frequency radars (HFRs). A total of six oceanographic surveys were organized in the area for deploying on the seabed, recovering, and re-deploying of three Acoustic Doppler Current Profilers (ADCPs) for a long period. Underway ADCP velocity measurements and drifting buoys release were a part of these surveys.

Although a relatively good assessment of the local hydrodynamics in Alderney Race was provided in numerous numerical studies (e.g., [4]-[6], [2], [3]), high quality tidal stream measurements in this area are scarce. This is due to extreme difficulties of *in situ* data acquisition. Bottom-mounted acoustic Doppler current profilers (ADCPs) are routinely used for measuring temporal variations of the tidal flow. However, deployment and recovery of ADCPs at sites with extreme current and wave climate is difficult. In this case, underway velocity measurements by towed or vessel-mounted ADCP offer a more practical alternative to fixed point observations.

In the majority of studies focusing on tidal stream resource assessment (e.g., [7], [8]), the velocity measurements are performed while the vessel follows the same track several times during a complete tidal cycle. If the site size is not large, current velocities recorded along the track allow to resolve spatial irregularities of the flow field. Alternatively, in the case of large site dimensions (~15 km in Alderney Race), wide gaps along the vessel tracks require measurements to be interpolated. Since underway ADCP measurements contain information on both spatial and temporal variations of tidal currents, these variations need to be separated from each other.

A number of techniques have been tested to date for this purpose (e.g., [9], [10], [7]). In the most recent study, Goddijn-Murphy et al. [7] showed that if a tidal model provides a reasonable estimate of flow field, an output of the model could be utilized to project the transect data to a fixed (central) time of the survey. More recently, Sentchev and Yaremchuk [11] used the more efficient Optimal Interpolation (OI) technique for reconstructing space-time evolution of the velocity field derived from towed ADCP surveys in the Boulogne harbor (English Channel). Their approach, which combines underway velocity measurements and modeling, provides a considerable improvement in assessing the tidal dynamics compared to what the model can do alone and offers a real opportunity for short-term monitoring of coastal currents.

In this work, considered as an extension of the previous study by [11], we provides examples of application of the OI technique to interpolate underway velocity measurements performed with a towed ADCP in Alderney Race. The performance of the method is assessed by comparing the optimally interpolated velocities with the independent data (static point ADCP measurements). The resulting velocity fields are then used for assessing the tidal stream resource in Alderney Race.

II. DATA AND METHODS

A. Study site – Alderney Race

The study site is the French sector of Alderney Race located west of the Cotentin Peninsula in Normandy, France (Fig. 1). The surveyed area is approximately 10 x 7 km square with water depth less than 60 m throughout the domain. The sea surface elevation there exhibits a wide range of variations (3.5-7m) depending on the tidal stage. According to modeling results, tidal variations of the sea level and currents are predominantly semi-diurnal and globally symmetric. Peak flood and ebb tidal velocities occur at high and low water respectively with slack water observed at mid-tide. The tidal current dynamics is thus referred to as progressive wave system. Tidal wave propagates northward during flood flow which lasts for 6 hours and then changes the direction to southward for the next 6 hours. Current speed variations over the neap-spring cycle are also large. At mean tide, the maximum tidal current speed (up to 3.5 m/s) is observed at the eastern side of Alderney Race [4]. Such strength of the current is due to the local acceleration of the tidal flow between Alderney Island and Cap de la Hague (Fig. 1). Spring tidal flow is extremely powerful. According to modeling results, the highest velocities (more than 5 m/s) are found again in the eastern sector of Alderney Race, in a large area extending up to 5 km off the French coast (e.g., [6], [2]).

B. Underway velocity measurements

High-resolution velocity measurements were performed using an experimental platform, carrying a broadband ADCP (600 kHz Teledyne RDI WorkHorse Sentinel) and towed by the R/V "Thalia". The platform is composed of an adjustable tail plane (with two vertical stabilization wings in the rear part) and a main front wing, connected together by two girders. The wing assures the maximum stability of the platform for a wide range of operational speeds (1-5 m/s) without generating tilts. During the surveys, the towed ADCP was located roughly 8.5 m below the water surface. Towing the platform at several meter depth aimed to maintain the ADCP as stable as possible under the water surface and below the influence of surface waves.

The velocity profiling was performed from 10 m depth to the sea bottom with the vertical resolution (bin size) of 1 m. The ADCP was set to operate at the pinging rate of 1 Hz. Each ping for velocity was composed of three sub-pings, averaged within 1-s interval, thus providing velocity error of 0.04 m/s. Single-ping bottom tracking was enabled to correct for boat's movement and the recorded velocities formed a current vector in the fixed frame relative to the bottom. The vessel's speed was typically 2-3 m/s for the majority of the tracks. The ADCP data were merged with navigation data provided by onboard GPS system also operating at 1 Hz.

A total of eight surveys were performed to assess the circulation pattern in Alderney Race. Only the results of two surveys are presented in this paper. Their tracks are shown in Figure 1 by solid colour lines. The first survey was performed on April 21, 2017 at 12:30–15:00 UTC, 2.5 hours before arriving high water (HW) in Goury, a small port closest to the surveyed area. The second survey took place the next day, on April 22. It was targeted at monitoring the currents during the ebb flow and lasted more than 5 hours from low water (LW)—3 hours to LW+2.25 hours. All surveys were performed during neap tide. This tidal stage was specifically targeted as the fieldworks were devoted principally to the deployment of the bottom-mounted ADCPs in the area. Underway velocity measurements were carried out between different steps of the sea trials.

The deployment of a bottom-mounted 600 kHz RDI ADCP in the surveying area allowed to supplement underway velocity measurements by current observations at a fixed point (red triangle in Fig. 1).

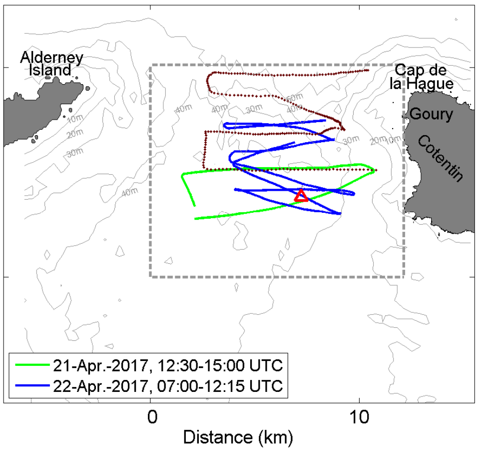

Fig. 1. Study area (gray dashed rectangle) located between the west coast of Cotentin (France) and Alderney Island (U.K.) with bathymetry, given in gray, and two towed ADCP surveys in April 2017. Surveys on April 21 12:30-15:00 UTC (green) and on April 22 07:00-12:15 UTC (blue) are used for detailed analysis of flood and ebb flow respectively. Brown dot line shows the track of another survey performed on flood tide in July 2018 (as an example). Red triangle denotes the location of the bottom-mounted ADCP.

Velocities were recorded from April 21 to June 03, 2017 every 5 min at 1 m vertical resolution starting from 2 m above the bottom. The mean depth was 45 m and velocity values in the surface 7-8 m thick layer, were removed from analysis because of signal contamination by surface waves.

C. *Optimal interpolation of velocity measurements*

Optimal Interpolation (OI) is a commonly used and powerful method of objective analysis of arbitrary spread observations. OI provides estimation of the spatial distribution of a physical quantity at a given time through a linear combination of the available data. This technique, pioneered by Gandin [12], was widely adopted in geosciences [11], [13]-[15].

The OI technique can be easily extended to include time dimension by using the space-time correlation functions. In this approach, the optimal correction to the evolution of a background vector field $\mathbf{u}_m(\boldsymbol{x},t)$ defined on a regular (model) grid is represented by a linear combination of the weighted differences between the background trajectory and the observed velocities. The weights a_i are chosen so as to minimise the mean square difference between observations $\mathbf{u}_i^*$ and the background field values $\mathbf{u}_m$, interpolated into the space-time locations of the observations by the linear operator $\mathbf{H}_i$, projecting gridded velocity values onto the i-th observation point from the apexes of the enveloping grid cell:

$$J_u = \langle [\mathbf{u}_m + \sum_i a_i(\mathbf{H}_i\mathbf{u}_m - \mathbf{u}_i^*)]^2 \rangle \rightarrow \min(a_i) \quad (1)$$

Here, angular brackets denote the statistical (ensemble) average, and summation is made over all (distributed in space and time) velocity values measured during the survey period. Given the space-time covariance matrices of the model $\mathbf{B} = \langle \mathbf{u}_m(\boldsymbol{x},t)\, \mathbf{u}_m(\boldsymbol{x}',t') \rangle$ and observations $\mathbf{R}_{ij} = \langle \mathbf{u}_i^* \mathbf{u}_j^* \rangle$, and assuming that observation errors are not correlated with the model (background) errors, the OI interpolation formula takes the form:

$$\mathbf{u}_{OI} = \mathbf{u}_m + \sum_{ij} \mathbf{B}\mathbf{H}_j^T \left(\mathbf{H}_i\mathbf{B}\mathbf{H}_j^T + \mathbf{R}_{ij}\right)^{-1} (\mathbf{H}_i\mathbf{u}_m - \mathbf{u}_i^*) \quad (2)$$

The OI takes explicit account of the expected spatial structure of both model and observational errors to produce the velocity field $\mathbf{u}_{OI}$ with the least error variance. The observation error covariance matrix $\mathbf{R}$ is assumed to be diagonal and contains variances σ^2 of the along track velocity samples taken at 1-minute intervals and typically ranged from 0.08 to 0.10 m/s with higher value observed from higher towing speed. The quantities $\mathbf{u}_m$ $(\boldsymbol{x},t)$ and $\mathbf{B}$, required in the equation (2), have been specified using the output statistics from the regional model MARS-2D [16], configured for high resolution simulations in the surveyed area and extensively validated in the earlier studies [5].

MARS-2D employs a nesting grid approach. Simulations are performed starting from a broad region and coarse resolution down to a small scale (local) domain covering a few tens of km with high resolution (110-m). The high resolution bathymetry (~100 m spacing) was provided by the Oceanographic Division of the French Navy (Service Hydrographique et Océanographique de la Marine, SHOM).

Tidal forcing was specified by prescribing sea surface height at large scale model open boundaries using 14 tidal constituents derived from FES-2012 (Finite Element Solution) which is a data assimilation product distributed by Aviso [17], commonly used in regional and global tidal models (e.g., [2]). The mean sea level was also prescribed at the open boundaries. Given very low wind and waves observed during the survey period, the corresponding forcing terms were not introduced in the model.

A bottom-friction parameterization was used with a variable in space-time drag coefficient, C_d, proportional to the bed roughness z_0 [16], set to be 0.015 m, and inversely proportional to the water depth. This provides C_d values which were found consistent with other estimates used in 2D tidal modelling (e.g., [18]).

In order to acquire statistics on tidal current variability (statistics contained in $\mathbf{B}$), twelve ensembles were generated from the model velocity time series. Each ensemble member contained either 2.5-hour or 5-hour long time series, sampled at 1 minute resolution in each grid point, corresponding respectively to the tidal stage of survey 1 (flood flow) and survey 2 (ebb flow). The respective background model trajectories $\mathbf{u}_m(x,t)$ were obtained by averaging over the twelve ensembles, either 2.5-hours long (flood flow) or 5-hours long (ebb flow), i.e., ensemble members are separated by exactly one tidal period. The space-time background covariance matrix **B** was computed using the same twelve ensemble members.

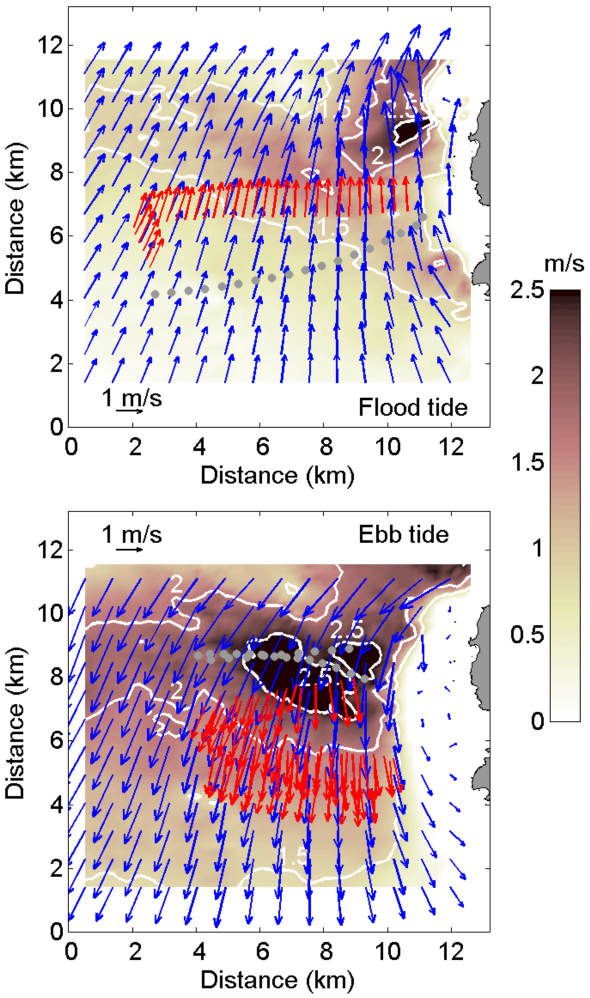

Fig. 2. Vertically averaged underway velocities (red vectors) recorded during the survey on April 21, 13:00-15:00 (upper panel) and on April 22, 08:15 to 12:15 (lower panel). Modeled velocity vectors (blue) and velocity magnitude (background shading) were taken at mid-time of each selected period: at HW-1.30h (upper panel) and LW-0.4h (lower panel). Gray dots represent the measurement points with velocity less than 1 m/s.

III. RESULTS AND DISCUSSION

Velocity profiles acquired during two surveys, on ebb and on flood tide, were one-minute averaged and geolocalized. The resulting distance between the thinned along-track data points varied within 120-180 m, depending on the towing speed. Mean velocity were then vertically averaged and compared with the velocities derived from the model output. For both surveys, underway ADCP measurements started just after the current reversal. Therefore, velocities recorded during the first 30-60 minutes were very low and were not used in comparison. Only velocities recorded from 13:00 to 15:00 on flood tide (survey 1) and from 08:15 to 12:15 on ebb tide (survey 2) were compared to the model output at the mid-time of the respective periods. Vector maps of modeled velocities corresponding to that mid-time on flood and ebb tide are shown in Fig. 2 (blue vectors). Location of areas with larger velocity is quite different for two tidal stages: on flood tide it is close to the shore, whereas on ebb tide it is approximately 5 km off the French coast. The velocity maximum is slightly less than 3 m/s in both cases, with much larger area of high velocity identified on ebb tide.

Observed current velocities are shown in Fig. 2 in red. Visual inspection reveals a good agreement for the direction and magnitude of the velocity vectors. During flood tide, the maximum discrepancy of the order of 0.1 m/s is found in the western part of the ADCP track. Thus, the model shows a general consistency with the observations for survey 1. On the contrary, during ebb tide survey, significant differences in current speed are observed at different locations. In order to take into account the tidal flow evolution during this survey period, the model-data misfit was estimated by performing space-time interpolation of model velocities into measurement points. The resulting discrepancy varied between 0.05 and 0.5 m/s, with the maximum value achieved in the central part of the surveyed area where the strongest currents occur. On average, the model overestimates the velocity magnitude by 20% during ebb tide whereas, during flood tide, the discrepancy is two times lower (11%).

The ultimate goal of underway velocity measurements is to assess spatial variability of the velocity field in the area and also to provide a valuable data set for comparison with the numerical model results. However, the observed currents are affected by temporal evolution of the tide over the survey period. To account for this, the data have to be interpolated in both space and time by using optimal interpolation. The resulting fields, reconstructed by OI, are a set of velocity snapshots generated on a regular space-time grid covering the entire period of observations. Fig. 3 shows an example of the interpolated velocity pattern at mid-times of the survey 1 and 2 (HW-1.30 hours and LW- 0.4 hours). The respective observations were projected to the mid-time by the OI method using space-time correlations of velocities provided by the model run for neap tide conditions. Note that they are also routinely projected to all other time intervals.

The absolute difference in velocity magnitude $\varepsilon = |\mathbf{u}_{OI} - \mathbf{u}_m|$ was estimated to quantify the overall agreement between the interpolated ($\mathbf{u}_{OI}$) and modeled ($\mathbf{u}_m$) velocity fields at mid-time of each survey. The best agreement is obtained on flood tide where ε is lower than 0.1 m/s in the majority of the domain with the exception of the north-eastern part where ε is ~0.5 m/s (Fig. 3, upper panel). Such a high difference might arise from large uncertainties in model bathymetry in this shallow water region. The more significant effect of the OI is revealed during the second (ebb tide) survey, where ε was found to vary from 0.3 to 0.5 m/s, revealing a large overestimation of current velocities by the model, especially in the central part of the domain (Fig. 3, lower panel).

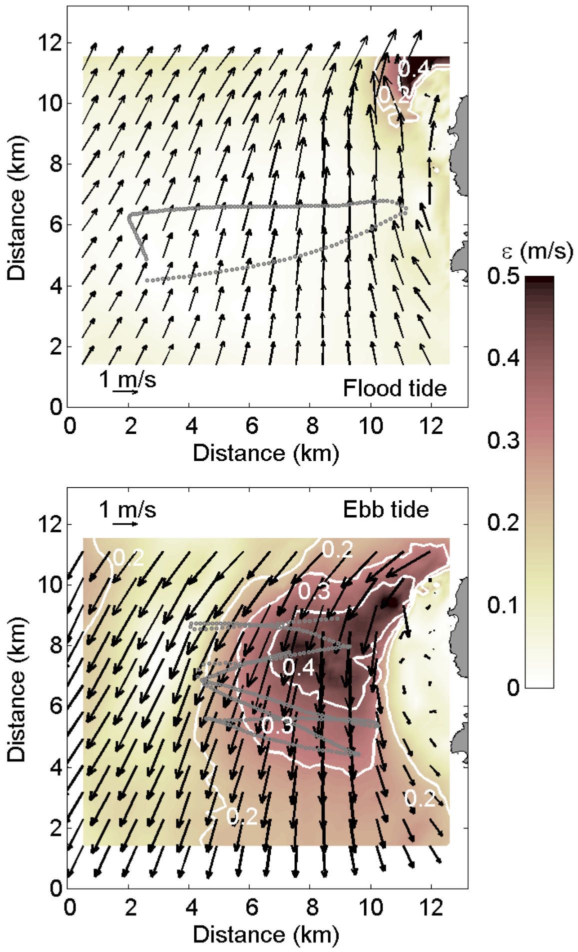

Fig. 3. Optimally interpolated velocity field obtained at mid-time of the first (upper panel) and second (lower panel) survey: HW-1.30h and LW-0.4h respectively. Background shading shows the difference ε between the modeled velocities and observed velocities optimally interpolated at mid-time of each survey period. Gray points represent the location of the 1-min averaged towed ADCP measurements.

The results shown in Fig. 3 help to recognize how good could be the velocity fields predicted by the model alone. Obviously, the model capability in reconstructing the tidal dynamics during flood tide is much better than during ebb tide. Larger discrepancy with observations (and larger model errors) is found in the area with strongest current which is of particular interest for tidal energy project developers. Fig. 3 shows the most likely velocity field (most consistent with observations), reconstructed at mid-time of the survey.

The interpolating skill of the OI method was then assessed by performing a space-time interpolation of the model velocities onto measurement points. The optimally interpolated and modeled velocities were thus compared point by point (Fig. 4) and the overall quality of interpolation was quantified by estimating the mean relative difference with the data.

$$e = \left(\sum_i (\mathbf{H}_i \mathbf{u}_\mathrm{m} - \mathbf{u}_i^*)^2 \Big/ \sum_i (\mathbf{u}_i^*)^2 \right)^{1/2} \qquad (3)$$

Fig. 4a shows that during flood tide, observed, modeled and interpolated velocity curves fit well. The only exception occurs around the 50th minute after the beginning of the survey, when the observed velocities suddenly decreased. We attribute these disturbances in current measurements to the change of the towing direction at that particular time. The overall difference between observations and the model results is low: e = 0.11. After performing optimal interpolation, the difference decreases to 0.09. Thus the model appears to be very effective in reconstructing the flood flow evolution.

Analysis of ebb flow velocities reveals higher level of discrepancy. The largest misfit (up to 0.5 m/s) is found at three consecutive cross-sections (central times 8:15, 9:15, 9:45 in Fig. 4b). It matches a geographic location approximately in the centre of the study area (cf. Fig. 3). The overall relative error during ebb tide is on the order of 0.2. Interpolation of velocity measurements provides a significant improvement of ebb flow field representation with a reduction of e down to 0.09 (i.e., by more than 50%).

In order to further assess the quality of interpolation and its ability to reproduce the time evolution of the flow field, the modeled and interpolated velocity time series were compared to velocities recorded by the bottom-mounted ADCP deployed within the survey area prior to underway velocity measurements (red triangle in Fig. 1). Velocities were recorded every 5 min at 1 m vertical resolution starting from 2 m above the bottom. The mean depth was 45 m and velocity values in the surface 7-8 m thick layer, were removed from analysis because of signal contamination by surface waves. Then the velocity profiles were depth averaged and time averaged within 10 min intervals. The resulting mean velocity values were compared to respective optimally interpolated velocities from towed ADCP survey and model outputs.

The comparison demonstrated that during flood flow a good match between modeled and observed velocities is reached. The overall relative error e is ~9% before OI of current measurements and the model was found to slightly overestimate the current speed. The optimal interpolation reduces the difference to 5%.

During the ebb flow, the absolute difference in current speed in the location of the bottom-mounted ADCP attains 0.5 m/s at peak flow. The relative error e for the whole ebb tide period is 18%. After performing the optimal interpolation, the overall agreement appears much better and the discrepancy e drops to 8%. This result and comparison with the independent source of data demonstrates the ability and efficiency of the OI technique in reconstructing tidal motions in highly energetic coastal areas.

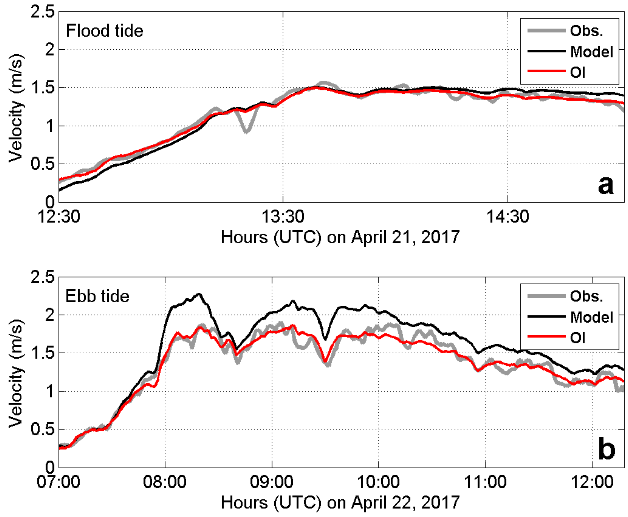

Fig. 4. Tidal current velocities from the model (black), towed ADCP measurements (gray), and after Optimal Interpolation (red), projected onto measurement points, for flood (a) and ebb tide (b). Observed velocities were depth-averaged.

IV. THEORETICAL POWER DENSITY IN ALDERNEY RACE

The kinetic power density is commonly used for tidal stream energy quantification. It is defined as

$$P = \frac{1}{2}\rho U^3 , \qquad (4)$$

where ρ is the seawater density and U the current speed. The spatial distribution of the kinetic power density $< P >$, averaged over the selected period of flood (April 21, 13:00-15:00) and ebb flow (April 22, 08:15-12:15), was assessed by using modeled and optimally interpolated velocity measurements (brackets mean time averaging). The results are summarized in Table I and spatial distribution of $< P >$ is given in Fig. 5 only for flood flow because larger discrepancy was identified at this tidal stage compared to flood flow.

Due to higher model capacity in reconstructing the flood tide dynamics, the spatial distribution of the kinetic power density and the location of the maximum of $< P >$ appear similar for both modeled and optimally interpolated velocity fields. The largest power density is found approximately 2 km off the French coast in both cases (results not shown). During ebb flow, the maximum power density is found at a distance of 5 km off the French coast. What is most important is the absolute difference in maximum power estimation after optimal interpolation of surveyed velocities. At both stages of the tidal cycle the maximum power density significantly decreased: from 11.5 to 8.5 kW/m² for flood tide and from ~10 to 7 kW/m² for ebb tide (26% and 33% decrease respectively) (Table I). The maximum value of power available in the flow is found larger at flood tide but the area of high power (> 6 kW/m²) is limited and does not exceed 2 km.

Conversely, the spatial extension of high power density area appears larger on ebb tide (Fig. 5a). An explanation for this is not trivial. Alderney Race is a tidal channel with a complex bathymetry. Although ebb and flood stages have approximately equal duration, at flood tide, the strongest current is confined to the shore, South-North oriented and aligned with it. At ebb tide, the tidal flow is driven by topographic features and propagates from the Northeast to the Southeast in a broader stream, at a larger distance from the shore. Moreover, flow amplification by local topographic features results in a different location of the velocity maximum and also in a different shape of power distribution. In particular, a broadening of large power density zone on the ebb tide can be seen in Fig. 5a.

Optimal interpolation of velocities results in a significant decrease of power density available in the flow. The spatial extension of large values of P (> 6 kW/m²) does not exceed hundred meters (Fig. 5b) with the maximum value of the order of 7 kW/m².

To further quantify the decrease in power distribution after application of OI technique, the power density was spatially averaged over the area covered by underway ADCP measurements (gray dashed rectangles in Fig. 5) and in time: during two- and four-hour long periods of flood and ebb flow, when current velocities were larger than 1 m/s. The mean value of power available in flood and ebb flow provided by the model ($\overline{P}_m$) appeared significantly different: 2 and 2.9 kW/m² respectively. After OI of the velocity measurements, the respective values of power ($\overline{P}_{OI}$) became 1.7 and 2 kW/m², showing smaller differences and significant reductions (15% and 31%) compared to pure model results $\overline{P}_m$ (Table I).

TABLE I
POWER DENSITY ESTIMATES FOR NEAP FLOOD AND EBB TIDE
MAX($< P >$): MAXIMUM VALUE OF THE KINETIC POWER DENSITY (KW/M²) TIME AVERAGED OVER THE SURVEYED PERIOD.
$\overline{P}$: POWER DENSITY, TIME AVERAGED AND SPACE AVERAGED OVER THE AREA COVERED BY UNDERWAY VELOCITY MEASUREMENTS.

	Flood tide	*Ebb tide*
Max($<P_m>$)	11.5	10.3
Max($<P_{OI}>$)	8.5	6.9
$\overline{P}_m$	2	2.9
$\overline{P}_{OI}$	1.7	2

How good is the agreement between our estimates of the kinetic power density with that provided in other studies? To give an example, the highest monthly mean value of P (13.5 kW/m²) was identified in the French sector of Alderney Race from numerical simulations by Telemac 2D model [2]. While in the most recent modeling study, Guillou et al. [3] evaluated the mean power density in the same sector as 12.5 kW/m². Separate estimates of the power density for neap tide conditions (period of the present study) were not documented. This

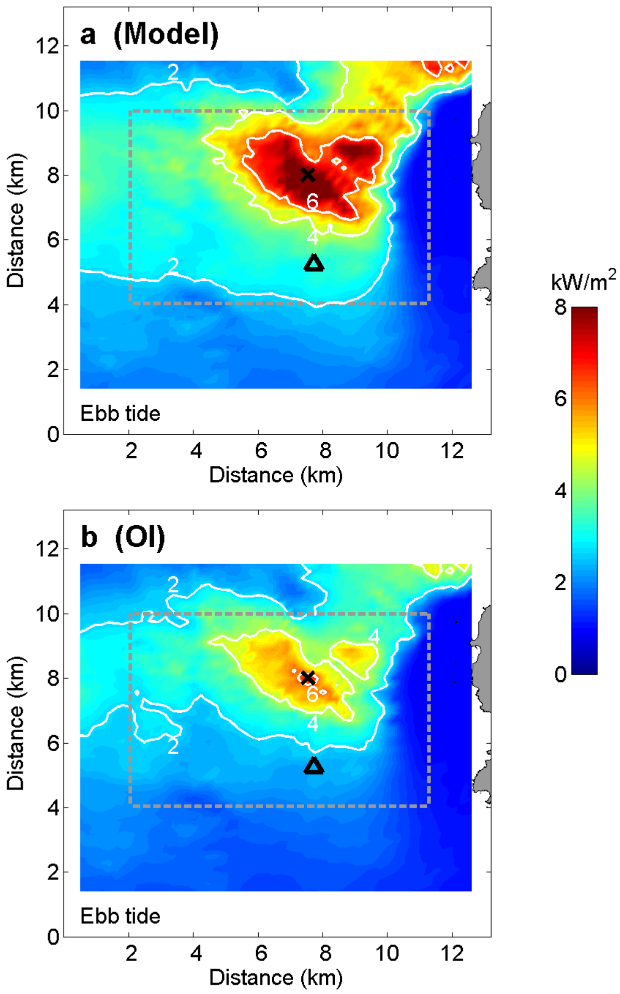

Fig. 5. Mean kinetic power density < *P* > derived from the model (a) and optimally interpolated velocities (b), and averaged over ebb tide period: Apr. 22, 08:15-12:15 UTC. Black crosses show the location of the maximum power density. Black triangle denotes the location of the bottom-mounted ADCP. Gray dashed rectangle shows the area covered by underway velocity measurements and used for spatial averaging of power estimates $\overline{P}$ given in Table I.

highlights the need of experimental validation of modelling results throughout the entire neap-spring period of the tidal cycle.

V. Conclusion

Underway ADCP measurements were used to assess the tidal circulation and tidal stream resource in Alderney Race – a highly energetic area where reliable, good quality measurements of tidal flow are scarce. Optimal interpolation was applied to process the velocity measurements from transect surveys at neap flood and ebb tide. The presented synthesis of the observed velocities with the MARS model post simulations provided a significant improvement in velocity fields both in terms of the reduction of model-data misfit and better consistency with independent (static point) velocity observations. As a consequence, a significant improvement in representation of the temporal and spatial variability of the tidal circulation was achieved. Constraining the model simulations by velocity measurements for evaluating the kinetic power density demonstrated a noticeable reduction of the energy resource especially during ebbing tide, compared to pure model estimates. This is a valuable result of application of the OI technique for processing the underway velocity measurements. ADCP measurements reported here were acquired only during neap tide conditions. The model trajectory cannot be constrained outside of the period of observations. Additional surveys should be organized on other stages of the neap-spring tidal cycle thus allowing comprehensive analysis of tidal stream resource variability on a regular basis.

In this research, we aimed to meet EMEC's recommendations to carry out transect surveys by towed ADCP in order to assess the spatial variation in the velocity field over the site. The OI technique applied to the surveyed data allowed us to go further in improving the quality of local resource assessment. We believe that merging high resolution velocity measurements and modeling makes the tidal stream potential estimation more accurate by reducing the uncertainties concerning the available resource at a tidal energy site. Thus we strongly recommend standardizing the OI method for resource assessment at other sites.

Even if OI has demonstrated its ability to significantly improve the assessment of tidal stream potential, the use of depth-averaged velocities may lead to inaccurate estimation of the energy resource. A good overall agreement between (a) optimally interpolated velocities and vertically averaged velocities from static point measurements, and (b) velocity profiles from underway ADCP measurements and bottom-mounted ADCP, offers an interesting possibility of reconstructing the entire 3D evolution of the velocity field within the tidal cycle. This could be a subject of future research requiring the use of 3D version of the tidal model.

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