Wake characterization of tidal turbines in the Pentland Firth using vessel-mounted ADCP measurements

M. Huchet, E. Droniou, L. Perez, F. Johnson, A. Baldock, B. Vermeulen, and C. Boake

Abstract — **Knowledge of the extension and velocity deficit induced by tidal turbine wakes is critical for the optimization of tidal farm layouts. The MeyGen project is the largest planned tidal stream energy project in the world. It is located in the Inner Sound, Pentland Firth, Scotland, and four tidal turbines are already installed. Site characterization campaigns were recently conducted to plan the deployment of additional tidal turbines, also providing a valuable opportunity to investigate wake dynamics at full scale. This work introduces a method using vessel-mounted Acoustic Doppler Current Profiles (ADCP) measurements to map the flow downstream of the existing turbines, and to identify and characterize the induced wakes. Crossflow transect measurements were conducted at various distances downstream from the existing tidal turbines, both at flood and ebb tides, with the turbine running or switched off, to assess the potential differences introduced by tidal turbine operation. Mean flow velocity estimates in the cross-section were obtained using an improved velocity solver that strongly reduces the spatial extent over which flow homogeneity must be assumed, which is a significant advantage for the investigation of tidal turbine wakes. To the authors' knowledge, this is the first time that this method has been applied to wake characterization in a tidal stream energy site. The mean velocity estimates obtained in each cross-section were compared for cases when the turbine was running or switched off. Findings reveal that vessel mounted ADCP transects, coupled with the dedicated velocity solver, provide a powerful tool for tidal turbine wake characterization.**

Keywords—**Tidal stream energy resource, wake characterization, Acoustic Doppler Current Profilers, vessel-mounted measurements.**

I. INTRODUCTION

WHEN investigating a potential tidal stream energy site, preliminary studies aim at estimating the undisturbed tidal stream resource, to ensure the feasibility of the project. Further studies then focus on providing more detailed and accurate information for the layout design. For large projects, the International Electrotechnical Commission (IEC) recommends including the impact of energy extraction by the planned Tidal Energy Converters (TEC) in the studies [1]. Indeed, significant energy harvesting from the tidal stream disturbs the flow in the immediate vicinity of the TEC. The extent and behaviour of the induced wake downstream the turbine must be thoroughly characterized, especially if the considered layout is a series of along-stream TECs, because a reduced flow velocity available at the downstream turbines will impact the estimated Annual Energy Production (AEP).

The impact of turbine operation on the surrounding flow is an evolving research topic, generally addressed through hydrodynamic modelling [2], [3]. Before site development, numerical simulations of the natural flow (without the TECs), carefully calibrated and validated against field data, are used as a basis, and a parametric term is then added to account for energy extraction. Although they produce useful first estimates, the existing methods for modelling energy extraction effects do not yet provide solutions accurate enough to assess intra-array effects between TECs [1].

However, measurements collected downstream of already operating tidal turbines could provide valuable insight into how energy extraction modifies the ambient flow conditions, especially at turbine-scale resolution.

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M. Huchet is at DynamOcean, Lannion, France (email: marion.huchet@dynamocean.com).

E. Droniou is at DynamOcean, Lannion, France (email: eloi.droniou@dynamocean.com).

L. Perez was at DynamOcean, Lannion, France (email: Larissa.perez@dynamocean.com).

F. Johnson is with the MeyGen Project, UK (email: fraser.johnson@meygen.com).

A. Baldock is at Baldock Energy, UK (email: andi@baldockenergy.co.uk).

B. Vermeulen is at Wageningen University & Research, the Netherlands (email: bart.vermeulen@wur.nl).

C. Boake is at Applied Renewable Research Ltd, UK (email: cuan@arrltd.co.uk).

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Such data would usefully complement and validate the numerical studies conducted to model the influence of TECs on the undisturbed flow.

In this context, the present paper introduces a method for studying wakes downstream tidal turbines using vessel-mounted Acoustic Doppler Current Profilers (ADCP) data. Crossflow transect measurements are collected at various distances downstream of the TEC. The single-ping, along-beam velocities are transformed into mean flow velocity estimates in the cross-sections using the "location-based" velocity solver developed in the *ADCPTools* suite [4]. Compared to the conventional "time-based" method, the solver provides improved flow velocity estimates because flow homogeneity is assumed in a smaller volume, thus decreasing the chances that this assumption will fail. The toolbox was initially developed for river applications, to study sharp bends [5] or sediment transport dynamics [6]. But it is also expected to prove very useful in mapping tidal stream energy sites as well, given the strong shear expected in the flow and the likely violation of the homogeneity assumption.

The method presented in this paper was tested at the MeyGen project site, which already has four turbines installed. Measurement campaigns were carried out to plan the deployment of additional turbines, offering a precious opportunity to also investigate the influence of the existing turbines on the downstream flow, and to study wake dynamics at full scale.

Vessel-mounted ADCP measurements are now commonly used to assess spatial variability across a site of interest [7]–[9]. But the only other example of mobile ADCP measurements in the wake of operating tidal turbines was found in [10], where the authors collected wake measurements in the along-flow direction, using ADCPs mounted on stream-following surface drifters. Additional transect measurements were conducted in natural flow conditions only.

To the authors' knowledge, the present paper is thus the first example of combining ADCP transect measurements with a state-of-the-art velocity solver to characterize the wake downstream operating turbines in a tidal stream energy site. This study aims to evaluate if the method can describe the flow finely enough to study the turbine wake. In this work, we compared mean flow estimates obtained in the cross-sections with the turbine running or switched off. Findings confirm that the method can be used to identify the wake and assess the induced velocity deficit.

II. METHODOLOGY

A. *MeyGen Project and study site*

The MeyGen Project is the largest planned tidal stream energy project in the world, aiming to develop up to 398 MW of installed power in the Inner Sound, Pentland Firth, Scotland. Previous characterization studies, such as [11], have shown that current velocities at the site may reach up to 5 m/s locally, which represents a great potential for power generation. More precisely, depending on the location considered, the depth averaged mean peak flow velocity is between 3.1 and 3.6 m/s for flood and between 3.1 and 3.4 m/s for ebb. The 50-year depth averaged current velocity is estimated between 4.4 and 4.8 m/s, for both flood and ebb flows. The flow runs towards approximately 125° from true North during flood tides, and towards ~270° during ebb tides, with some spatial variability across the site. According to previous measurement campaigns [11], at peak flow speed the mean streamwise turbulence intensity at mid-height of the water column is around 12% during flood tides and 10% during ebb tides.

During Phase 1 of the project, four 1.5 MW turbines were installed on the seabed, using gravity-based support structures. Phase 1 commenced construction in 2014 and began operation in 2018. During Phase 2, site characterization campaigns were carried out to plan the deployment of additional turbines, representing 28 MW of tidal power capacity with a target commissioning date of 2027. It is expected that this array will utilize some turbines with a capacity of 3 MW. Phase 3 will see the remainder of the consented project delivered. Given the award of 28MW in AR4, MeyGen has an additional consent for 52MW. Phase 4, in planning, will seek to expand the consents and build out the remaining 312 MW.

The datasets analysed in this paper were collected during Phase 2 field campaigns.

B. *Field campaign design*

The campaign consisted in deploying a vessel mounted ADCP to perform series of crossflow sections downstream of turbines 1 and 4 (hereafter labelled T1 and T4), to assess the mean flow characteristics. The instrument used was a 600 kHz Teledyne Workhorse Monitor, configured with 50 measurement cells of 1 m and set to continuously sample along-beam velocities at 1 Hz. The Doppler noise on single-ping horizontal velocity components for this instrument, with along-beam ambiguity velocity of 3.5 m/s and bin size of 1m, is estimated at 9.6 cm/s by Teledyne software PlanADCP. In addition, heading information and GPS positions were provided by a GNSS system simultaneously deployed during the campaign. Its heading performance is better than 0.30° RMS and the positioning accuracy is 0.6 m 95% of the time.

Transects downstream of T4 were conducted during flood and ebb tides, at various distances from the turbine on the along-flow axis. T4 is located at (58.6582088°N; 3,1372297°W). For both tidal stages, 10 nominal sections were defined, providing target tracks perpendicular to the mean flow direction. They cover an area spanning from two turbine diameters upstream the turbine (labelled -02D) to twelve diameters downstream (+12D). The turbine diameter considered is 18 m, meaning that e.g., the transect labelled E+04D was conducted $4 \times 18 = 72$ m downstream of the turbine during ebb flow. The series of 10 cross-section measurements were carried out sequentially, first with the turbine running, then turned

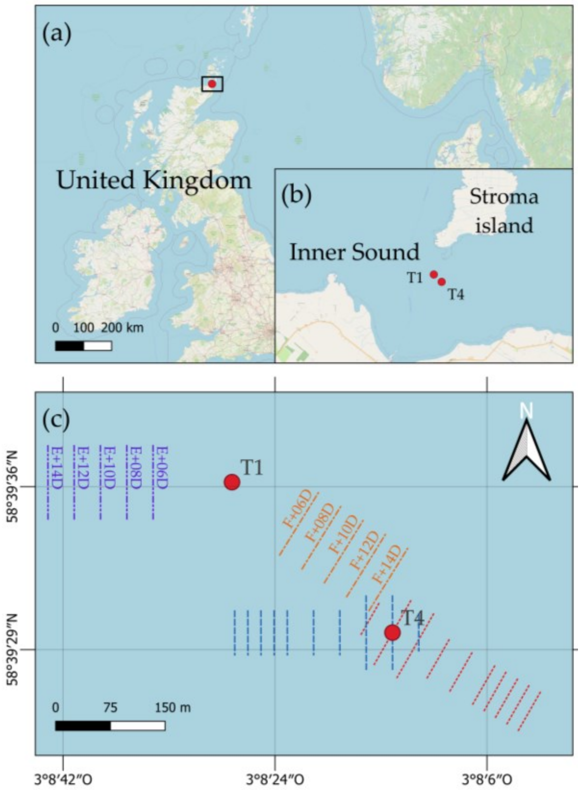

Fig. 1. MeyGen Project location within (a) the United Kingdom, (b) the Inner Sound, and (c) top view of target transects tracks downstream of turbine 4, for both tides: flood in orange for T1 and red for T4; ebb in purple for T1 and blue for T4. The red circles indicate the locations of the installed turbines. The dashed lines show the nominal section coordinates and are labelled according to the tidal stage and distance to the turbine: "F+06D" reads as "section located 6 diameters downstream the turbine, at flood tide".

TABLE I
TRANSECTS MEASUREMENTS

Turbine	Transect
T4	F-02D; F+00D; F+02D; F+04D; F+06D; F+08D; F+09D; F+10D; F+11D; F+12D E-02D; E+00D; E+02D; E+04D; E+06D; E+08D; E+09D; E+10D; E+11D; E+12D
T1	F+06D; F+08D; F+10D; F+14D E+06D; E+08D; E+10D; E+14D

off, to investigate differences in flow patterns. At each of the 10 cross-sections considered, transects were repeated 5 times in a row, to be able to average out turbulence induced fluctuations and thereby allow for a better accuracy of the estimated mean flow.

Measurement collection during a set of 5 repeated transects at a given location lasted between 5 and 10 minutes. Completing a whole lap of measurements spanning the 10 defined sections (from -02D to +12D) took around 1 hour.

Transect measurements were also collected downstream of T1. The methodology was the same as for T4, except that instead of going through all cross-sections with the turbine running then switching the turbine off and completing the same scan again, this time the series of

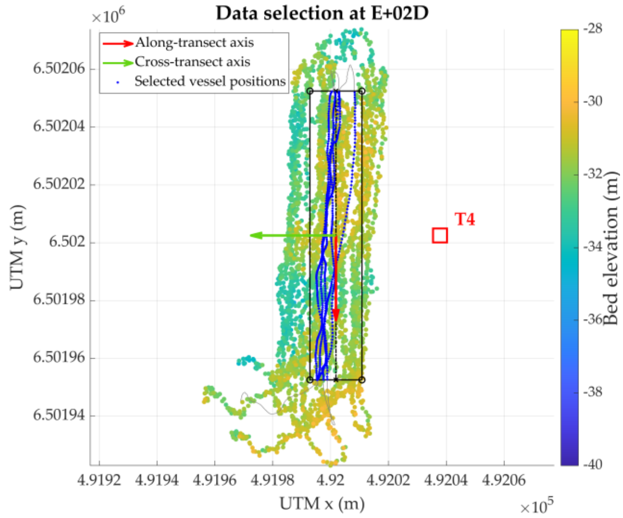

Fig. 2. Example of data selection, for transect E+02D. Coloured dots show the bed elevation measured using bottom-track by the four slanted beams, for the whole dataset. The black rectangle shows the target area, centred on the nominal transect track. The blue dots show the vessel positions which fall within the target area, and for which the corresponding velocity data are kept for the analysis. The arrows define the local coordinate system associated to the cross-section studied, with tangential (red) and normal (green) axes.

transects were measured at a given cross-section with the turbine on, then repeated immediately after with the turbine off, before moving to the next cross-section. A few minutes separated the two sets of measurements at the same section to avoid measuring a transient flow. This ensured that for each cross-section considered, both states of the turbine were sampled roughly at the same time.

Fig. 1 shows: (a) the location of the MeyGen site in the UK, (b) the Inner Sound, between mainland Scotland and the island of Stroma, with the location of turbines 1 and 4 which were deployed during Phase 1, and (c) the target tracks of the transect conducted downstream of turbine 4 (T4) at each tidal stage. Table I lists the names of the transects conducted for each turbine considered.

C. *Data QC and selection*

The raw beam velocity data were processed using the *ADCPTools* MATLAB toolbox, made publicly available by Vermeulen et al. [5]. The toolbox offers an integrated processing chain for mobile ADCP data. More importantly, it provides a state-of-the art velocity solver, which computes the mean flow velocity from raw vessel-mounted ADCP data. This solver is particularly useful when studying repeated transects, because it strongly reduces the spatial extent over which homogeneity is assumed when processing velocity data, thus enhancing the accuracy of the analysis and allowing to more finely resolve the structures of the flow.

In addition to the quality checks already performed internally by the instrument during data acquisition, beam velocities associated with a correlation value below 64 counts were discarded, as recommended by Teledyne RDI.

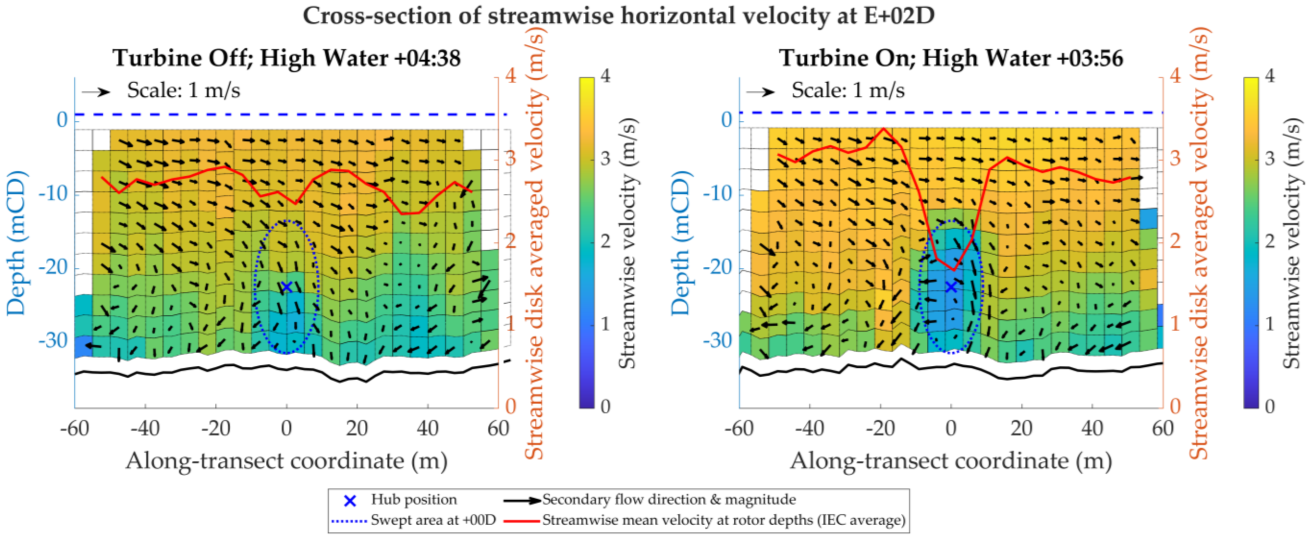

Fig. 3. Cross-section plots of streamwise velocity at ebb tide, 2 diameters downstream of turbine 4. Left: with T4 turned off; Right: with T4 running. Black arrows indicate the secondary flow. Red curve, associated to the secondary right y-axis, shows the streamwise component of the rotor disk averaged velocity (not scaled for flow time variation).

Vessel-mounted ADCP data were corrected for the ship velocity using GNSS information.

Beam velocity data were referenced to Chart Datum (CD), which is assumed equal to the Lowest Astronomical Tide (LAT) here. The transducer depth and the varying water levels due to tides were also accounted for, as allowed by *ADCPTools*. The LAT value and the water level time series were provided as a result of the harmonic analysis of a seabed-mounted ADCP dataset collected nearby, briefly described in [12].

Then, suitable velocity data points were selected for a given cross-section by combining the vessel's track with a target area. This area was defined as a rectangle, centred on the targeted vessel path, as illustrated in Fig. 2. Its crossflow dimension is the length of the nominal section, and its along-flow dimension is 1 turbine diameter long (18m). A complementary selection criterion made sure that the velocity data in the target area were collected at a consistent time for the cross-section considered. All selected data points were used to solve for the velocity in the considered cross-section.

D. *Computation of velocity characteristics*

The aim of the analysis is to get the mean flow characteristics from the radial velocities collected during transects measurements. The mean flow velocity represents the average of the velocity data collected over the time span of the transect measurements, which were repeated 5 times for each cross-section.

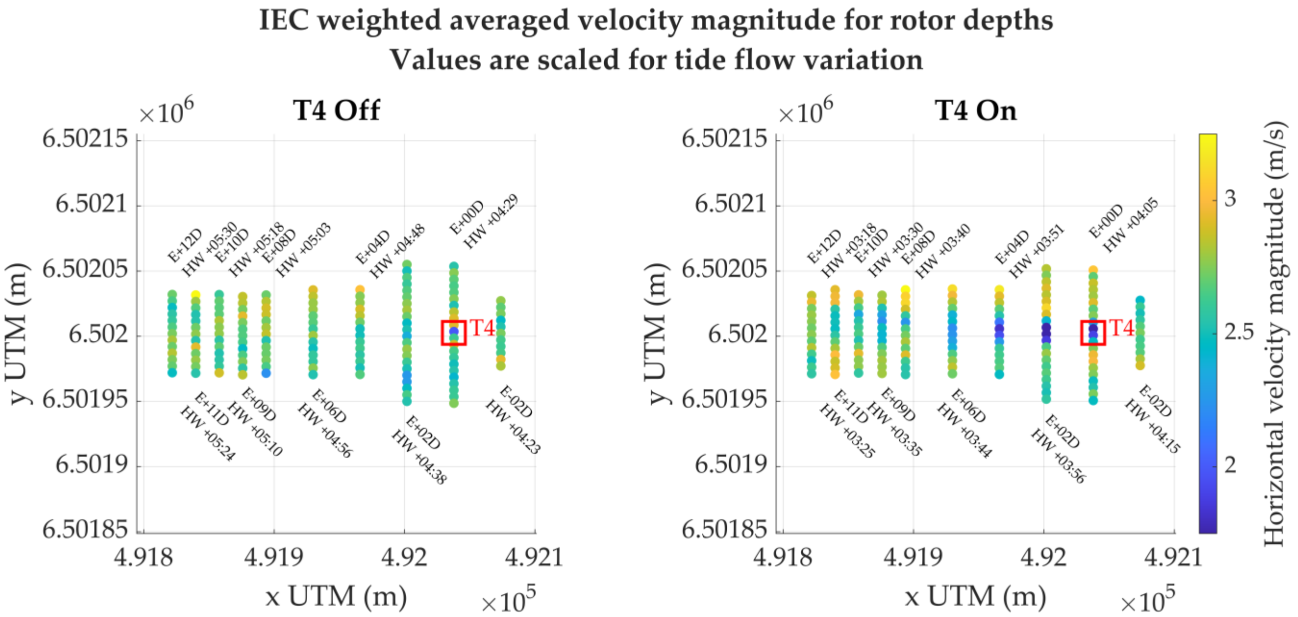

Fig. 4. Top view of rotor disk averaged velocity magnitudes downstream of T4 turbine, at ebb tide. Left: with the turbine off. Right: with the turbine running. Both subplots share the same color scale. In the labels associated to each section, "HW" stands for "High Water". The reference velocity at T4 used for the scaling was taken at HW+04:23 for T4 Off (section E-02D), and at HW+03:18 for T4 On (E+12D).

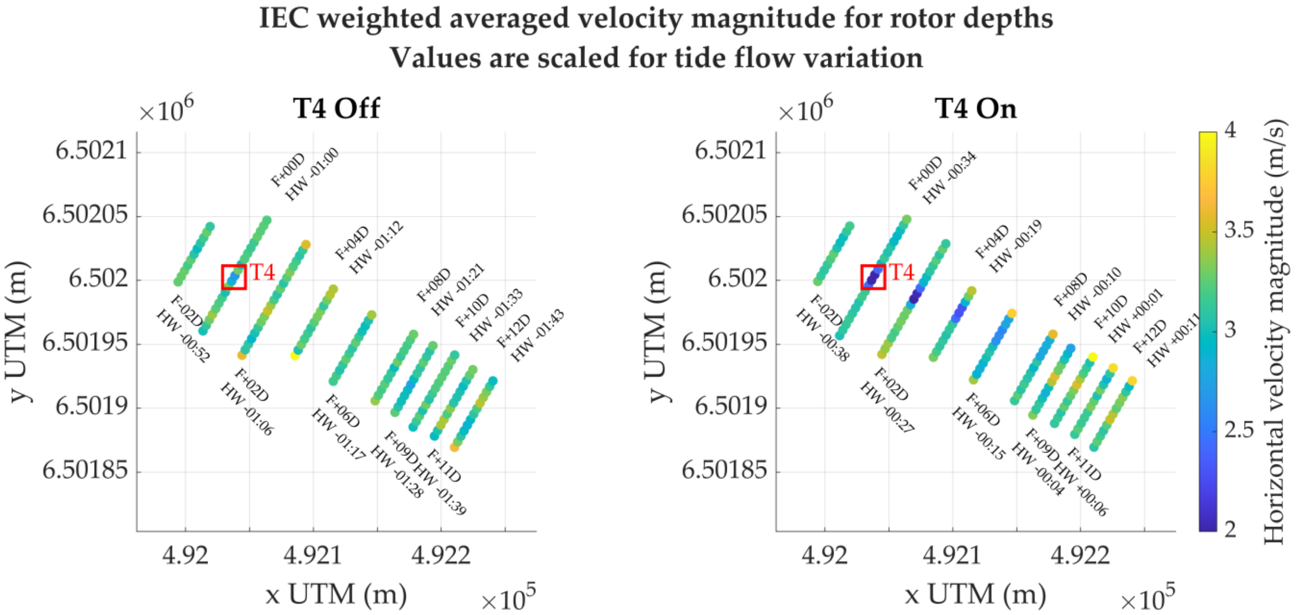

Fig. 5. Top view of rotor disk averaged velocity magnitudes downstream of T4 turbine, at flood tide. Left: with the turbine off. Right: with the turbine running. In the labels associated to each section, "HW" stands for "High Water". The reference velocity at T4 used for the scaling was taken at HW+01:43 for T4 Off (section F+12D), and at HW-00:38 for T4 On (F-02D).

In *ADCPTools*, a 2D mesh was generated, with a $\Delta n = 5\,m$ lateral resolution and a $\Delta z = 3\,m$ vertical resolution. The mesh divides the considered cross-section into small volumes and assigns each velocity data point (collected from several transects) to a given mesh cell. All radial velocities associated to the cell are used to solve for the flow velocity in that cell, following the method described in [5]. In the present study however, if less than 25 radial velocity data points were available within a cell, the corresponding result was discarded.

A local reference frame was also defined for each cross-section considered, with its tangential axis aligned with the target transect track and its origin set at the middle of the nominal transect. The mean velocity obtained as an output of the solver can be expressed as ENU components, or as tangential and normal components in this local reference frame.

E. Quantities compared

The analysis of the vessel mounted ADCP dataset provided the 3 components of the Eulerian velocity in every cell of all cross-sections considered.

To assess the influence of the wake at rotor heights, weighted rotor disk average velocity magnitudes were also computed using the "method of bins" defined by the IEC [13]:

$$\overline{Vel_{Disk}}(t) = \left[\frac{1}{A} \times \sum_{z=8}^{z\ bottom\ tip} Vel^3(t,z) \times A_z\right]^{\frac{1}{3}} \quad (1)$$

Where the overbar represents a spatial average over the rotor swept area, A is the total rotor swept area, z represents the cell depths in mCD which are within the rotor swept area and A_z is the portion of the rotor swept area which is within the cell located at a distance z mCD. A rotor disk diameter of 18 m was used.

As previously stated, completing a lap of transect measurements over 10 cross-sections takes approximately an hour. This is long enough for the tide to change, so the measured velocities tend to increase or decrease with time within a given lap: this complicates the identification of potential wake effects. To cope with this, a scaling factor is then applied to the depth-averaged velocities when comparing the results from several sections in a single plot. It is computed using the time variation of a known reference: the mean velocity measured at T4 by an independent, turbine mounted ADCP, denoted V_{T4}. The reference value is taken during the first transect of the first section at time t_0. For a section measured at any time t, let us call $V(x,t)$ the depth-averaged velocity obtained at along-transect coordinate x. This depth-averaged velocity is corrected for the influence of tide variation using:

$$V_{corrected}(x,t) = V(x,t) \times \frac{V_{T4}(t_0)}{V_{T4}(t)} \quad (2)$$

This scaling is applied within a lap of transect measurements (spanning 10 sections at a given tide stage) and the value of $V_{T4}(t_0)$ is not the same from one lap to another.

III. Results

A. Downstream of turbine T4

The methods produced the mean flow velocity in the cross-sections considered. As an example, Fig. 3 presents the results obtained for the section +02D downstream of T4 which was sampled during ebb tide. It provides a

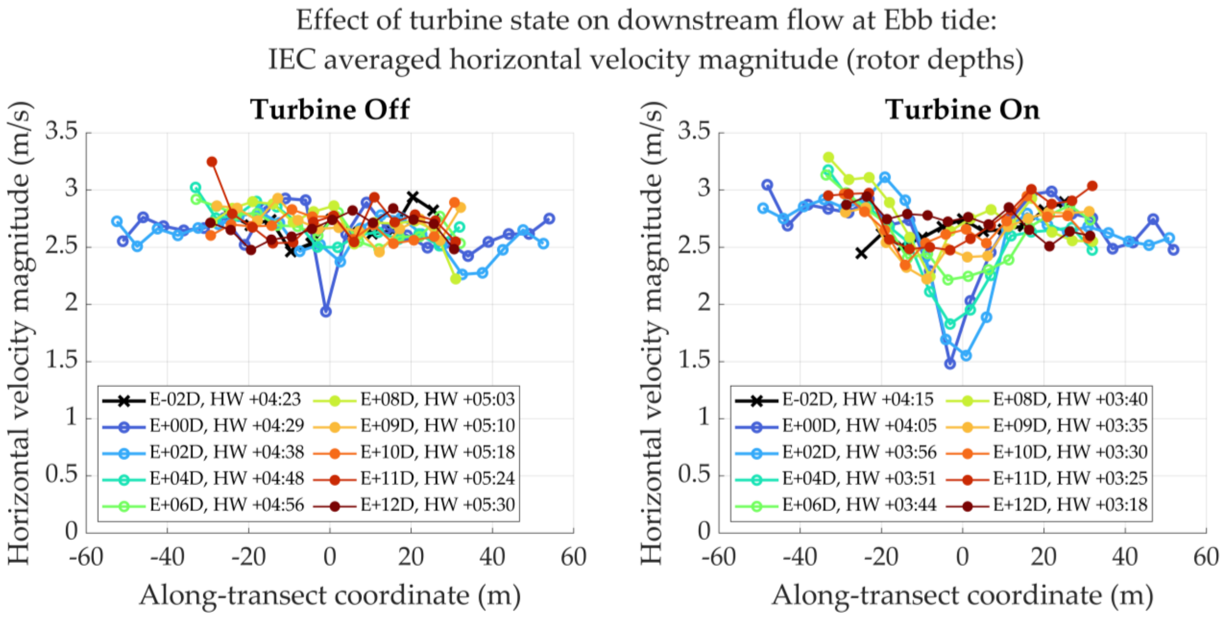

Fig. 6. Superimposed rotor disk averaged velocities, scaled for tide variation. Results are shown for measurements collected at abb tide.

comparison of the flow characteristics downstream of the turbine when it is running and when it is turned off.

The colour plot shows the streamwise component of the velocity in each mesh cell, while the black arrows show the velocity estimates in the cross-stream and vertical direction. The blue cross and blue circle respectively mark the upstream hub position and rotor swept area. Each plot also features a double y-axis: the left y-axis (in blue) indicates the depth of each cell, referenced to Chart Datum. The right y-axis (in red) relates to the red line superimposed on the colour plot. This red curve shows the value of the streamwise component of the rotor disk averaged velocity, calculated using (1). Here, as shown in the left-hand side of the figure, a minor velocity deficit is present at 2D downstream of the turbine even when it is not running, which is probably due to the turbine structure itself.

The velocity deficit is much stronger when the turbine is operating (right-hand side), and the influence of the wake is clearly visible both with the drop in the averaged velocity, and with the associated flow pattern at rotor height. The figure illustrates the ability of the implemented method to provide a detailed insight into the flow characteristics at a given section.

In addition, Fig. 4 and Fig. 5 show bi-dimensional maps of the rotor disk averaged velocity magnitudes, corrected for tide flow variation, when T4 is turned off (left) or running (right). The estimates were computed from measurements taken during ebb and flood tides for Fig. 4 and Fig. 5, respectively. Here, we consider that the flow has recovered when the minimum rotor disk averaged velocity magnitude in the section reaches 90% of the mean upstream horizontal velocity magnitude (a commonly used value). Using this criterion, when the turbine is turned off, the flow has recovered at +02D downstream for flood tide and at +04D for ebb tide. When the turbine is operating, the wake persists up to +09D downstream for flood and up to +10D downstream for ebb.

In addition, during flood tides, the wake clearly deviates towards the North as the flow moves away from the turbine. The wake's trajectory is not as clear at ebb tide. But a complementary chart superimposing the rotor disk averaged velocities at several cross-sections, shown in Fig. 6, shows here again that the wake persists up to +10D i.e., further away from T4 than during flood tide, and deviates towards the North (towards the negative coordinates along the tangential axis of the local reference frame, see Fig. 2).

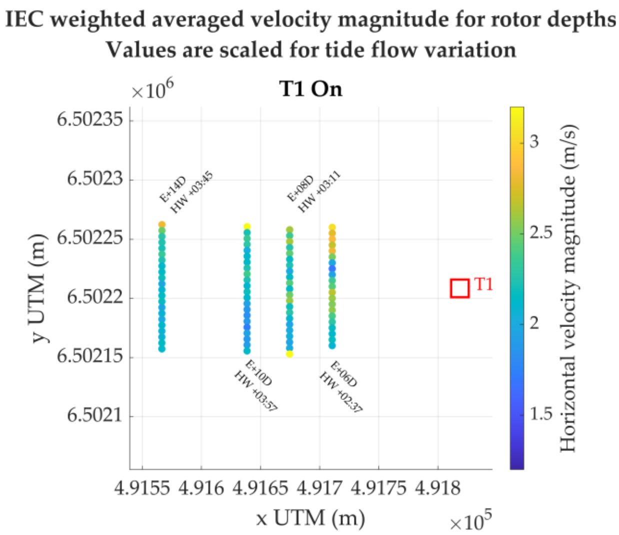

Fig. 7. Top view of rotor disk averaged velocity magnitudes downstream of T1 turbine, at ebb tide, with the turbine running. Values are scaled for the effect of tide variation. The reference velocity at T1 used for the scaling was taken at HW+02:37 (E+06D).

B. *Downstream of turbine T1*

The vessel mounted ADCP datasets collected downstream of T1 were processed in the same way as for T4 datasets. Fewer cross-sections were studied, but in this deployment special care was taken to minimize the time between measurements collected with T1 On and Off at a given cross-section. This was done by alternating between measurements with T1 On and Off at a given section, after waiting a few minutes between the two sets of measurements at the same section to avoid measuring a transient flow disturbed by the turbine's change of state. This procedure aimed at reducing the influence of tidal variation on the results. Fig. 7 shows the location of the cross-sections studied, and presents the results obtained on disk-averaged horizontal velocity magnitude, for measurements collected at ebb tide with T1 running. In this figure, the results are scaled to account for tidal variation because measurements at +14D were collected more than an hour later than measurements at +06D. The velocity measured at T1 (by a turbine mounted ADCP) at HW+02:47 was used as a reference to compute the scaling factor.

Finally, Fig. 8 displays the rotor disk averaged streamwise velocity at four distances to the turbine, at ebb tide. Each subplot is dedicated to a cross-section and compares the results for T1 turned off (blue, dotted line) and for T1 running (orange, solid line). Because measurements with T1 running or turned off were intertwined during data collection, less than 15 minutes separates the data collected for T1 running or turned off at a given section. Therefore, no scaling factor is applied to compare these results.

The velocity deficit Is still present at +06D downstream of the turbine when T1 is running, but as expected there is no visible pattern when it is not operational. Results at E+08D suggest a small velocity deficit may remain, but the flow seems to have recovered at E+10D, where no visible difference can be identified between both states of the turbine.

Results obtained at flood tide (not shown here) must be taken with caution because data were partly collected at low flow (velocity was below 1.5 m/s for the +10D section). However, findings suggest a similar influence of the wake, with a velocity deficit visible up to +08D downstream of T1.

IV. Discussion

A. *Method performance*

When developing a tidal stream energy site, accounting for the energy extracted by the operating turbines and its consequences on the surrounding flow is a challenging task, because very little data is available to validate the numerical models simulating the array of tidal turbines. Here, a survey method combining ADCP transect measurements with an accurate velocity solver was tested downstream of operational tidal turbines, aiming to provide insight into the wake's behaviour.

Our results showed a clear distinction between the flow characteristics downstream the turbine when it is operating and when it is turned off, with a strong velocity deficit attributed to the functioning of the rotor. The vertical mapping of the wake in cross-sections immediately downstream the turbine is a striking result of the method, with the associated flow pattern clearly

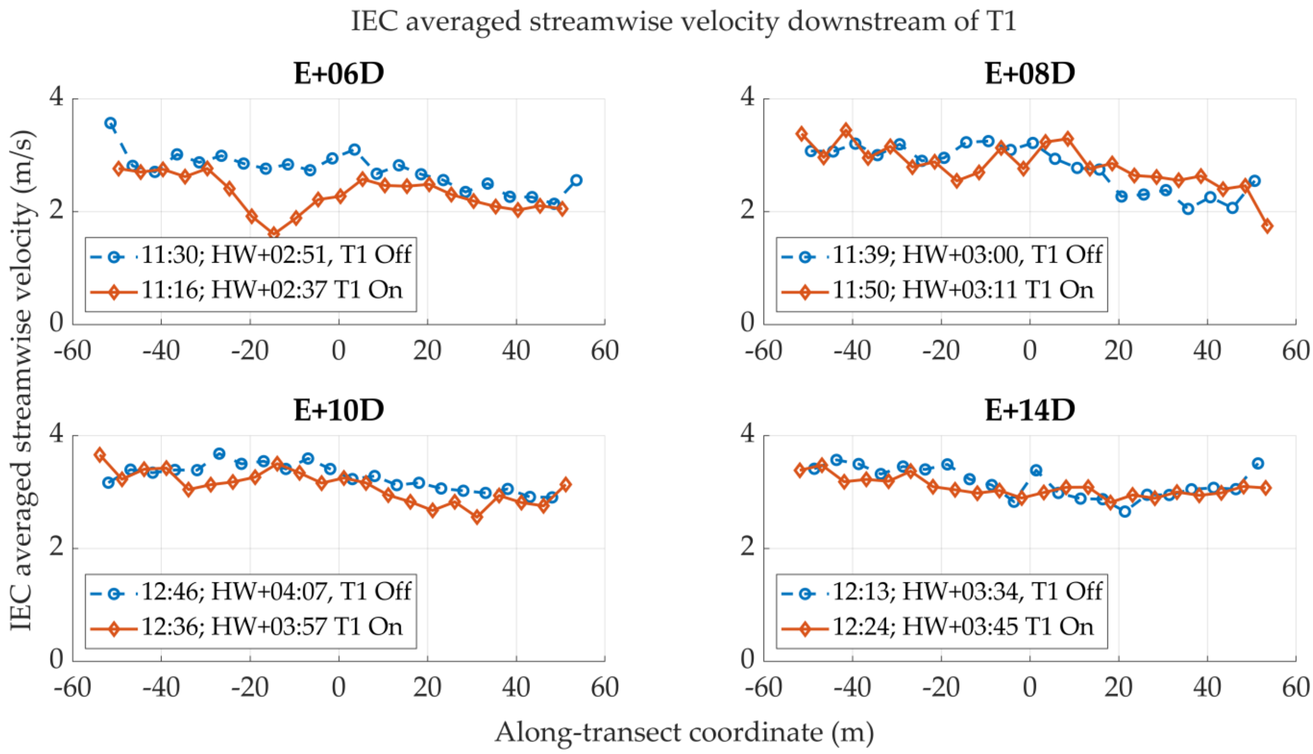

Fig. 8. Comparison of (unscaled) rotor disk averaged velocities downstream T1 at ebb tide, with the turbine running vs turned off.

identified in Fig. 3. To the authors' knowledge, the data presented in this figure are the first example of a tidal turbine wake section studied using vessel mounted ADCP measurements. The technique also allows the assessment of the evolution of the wake downstream the turbine, as shown by the top view maps of the rotor disk averaged flow velocity presented in Fig. 4, Fig. 5 and Fig. 6.

These results confirm the relevance of the investigated method, using vessel mounted ADCPs for wake characterization downstream a tidal turbine. Our study usefully complements previous attempts of tidal site characterization using mobile devices [10], with the novelty that here ADCP transect measurements were used to compare the undisturbed and disturbed mean flow[1] downstream a tidal turbine, and to study the induced wake.

Moreover, processing the ADCP data with the location-based velocity solver seems to give more accurate results than when using the conventional, time-based method. Fig. 9 presents the estimates of streamwise velocity in the cross-section located +02D downstream of turbine T4, at ebb flow, obtained from both methods. As shown in the figure, the velocity deficit is more pronounced in the results obtained with the location-based method, in line with the tendency of the conventional method to spatially smooth the velocity estimates.

B. *Limitations and future work*

To better evaluate the potential of the method, the accuracy of the obtained velocity estimates still needs to be thoroughly assessed. It is dependent on the ADCP measurements uncertainty and Doppler noise, and on the uncertainty on the position and heading of the vessel mounted ADCP (obtained from the GNSS system used in the measurement campaign). Estimates of these measurement uncertainties are provided by the manufacturers for the equipment used. However, the final uncertainty on transect results, including the influence of vessel motion and of using the new analysis method by [5], has not yet been estimated. Future work should include a validation of the method by comparing the obtained mean flow estimates with data from a seabed mounted ADCP, or any other device providing velocity measurements in the cross-section. Another recently submitted work compared velocity estimates obtained from vessel-mounted ADCP measurements with data from a seabed-mounted ADCP collected simultaneously [12]. The study was conducted in the Inner Sound as well and showed that the results agreed very well. Although the survey method and underlying objectives were different from transect measurements, the uncertainty of the VMADCP surveying method itself is thus expected to be low.

Besides, the accuracy of the method is enhanced when using several transects in a row for a given section, to decrease the uncertainty associated with the measurements. With 5 repetitions retained as a good compromise, this implies that 5 to 10 minutes are needed to scan a 100 m long section. Therefore, the tide changes as the studied site is being sampled. Its influence may be removed to get pseudo-snapshots by using a tidal scaling, as done here, but the accuracy of this technique must be further evaluated. When interested in assessing the consequences of turbine operation, it is then advised to collect measurements with the turbine turned on then off as close in time to one another as possible – noting that this reduces the time available for data collection due to the need to wait for steady state conditions to reoccur.

Finally, this survey method represents a valuable complement to classical site assessment studies, because its outputs can be used to validate numerical models simulating energy extraction by the turbines and evaluating the total AEP of the array. This was however outside the scope of the work presented here.

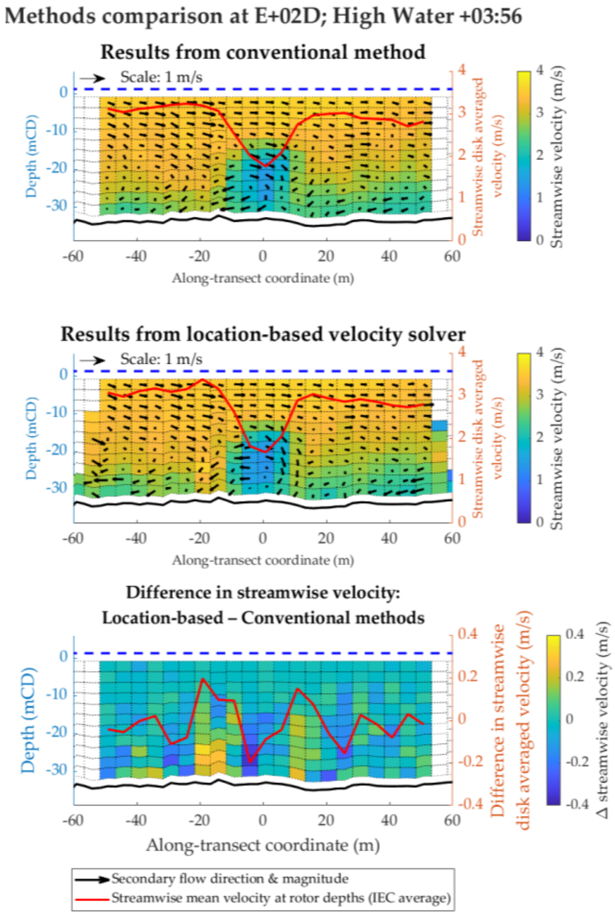

Fig. 9. Cross-section of streamwise velocity at +02D downstream TTG4, at ebb tide: comparison between both methods. Top: results for the conventional, time-based velocity solver. Middle: results for the improved, location-based velocity solver. Bottom: difference in the obtained streamwise velocity.

[1] Note that the instrument used was a four-beam ADCP and no assessment of turbulence metrics was conducted.

V. CONCLUSION

The present study introduced a new method for studying the wake downstream operating tidal turbines. It relies on a vessel mounted ADCP and a GNSS system to perform several repetitions of transect measurements at various crossflow sections. This measurement technique, combined with the improved "location-based" velocity solver, provides a refined description of the turbine wake's spatial variability and a better understanding of its behaviour. The obtained velocity estimates could also be used to validate numerical models studying the influence of energy extraction.

Mean flow estimates in the studied cross-sections were computed from raw measurements using the dedicated velocity solver. Results show that the investigated method is able to finely map the mean flow in the turbine wake and its surrounding area. More importantly, it clearly differentiates between situations when the turbine is running and when it is not. Crossflow transect measurements allowed to identify the wake induced by the operation of a tidal turbine, to evaluate the associated velocity deficit and to follow the flow disturbance as it moved away from the device. Maps of the average flow velocity showed that the influence of the operating turbine was visible up to at least 6 diameters downstream of the device, and even up to +10D for one of the turbines during ebb tide.

These promising findings still need to be consolidated with a thorough analysis of the sources of uncertainty, and the difficulty of comparing measurements taken at different moments of the tidal cycle in a site with strong variations was emphasized.

With these precautions in mind, our results show that the presented method is a useful tool to assess natural flow variability across a given site, but also to collect more information on the behaviour of wakes in operating tidal farms. Better knowledge of how the energy extracted by the turbines influences the surrounding flows could help optimize tidal farm layouts and enhance total power production.

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