Supergen Offshore Renewable Energy

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WTIMTS – Wave and Turbulence Interaction and Measurement at a Tidal Site

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1 Introduction

Fatigue in tidal energy converter (TEC) blades and structures is mainly a result of fluctuating hydrodynamic loads due to a combination of turbulence in marine currents and wave action [1]. Since operations and maintenance is the biggest technical cost associated with tidal stream power [2], understanding these phenomena is an important step in cost reduction for the sector. Most observations of currents at tidal stream energy sites rely on acoustic Doppler current profilers (ADCPs). ADCPs give very robust estimates of mean flow [3], but have trouble distinguishing between wave and turbulence effects when both phenomena are present at a particular site. WTIMTS was a project to explore a new method of separating out waves and turbulence; specifically, to determine the contributions of each of these two phenomena to estimates of turbulent kinetic energy (TKE) obtained from ADCP measurements.

Previous studies that have aimed to separate wave and turbulence effects have typically pursued either a spectral approach (see for example [4]) or a statistical approach (see for example [5]). The motivation behind WTIMTS was the realisation that both of these approaches could be applied to the same data with relatively little difficulty, as they are applied to different stages of the data treatment. Specifically, spectral filters are applied to the velocity time series recorded by the ADCP before calculating TKE, while statistical filters are applied to the derived TKE values after they have been calculated from the velocity records.

2 Aims and objectives

The aims of WTIMTS reflected the expected development path of the combined spectral-statistical method: starting with the development and testing of the method implementation by applying it to a previously-analysed dataset; then extending this to other sites and virtual datasets; producing a version of the tool that is freely accessible and documented; and finally using the tool to investigate the relationship between wave activity and turbulence production. The specific objectives tied to these aims are:

1. ***Develop and test*** the combined spectral/statistical method for estimating TKE and turbulent lengthscales, using a single ADCP dataset as a case study
2. ***Benchmark*** method developed in SO1 against Supergen ORE Core Research virtual site synthetic dataset

3. ***Compare*** wave-turbulence decompositions for 3 additional real data sets (1 from an industrial partner, 1 from an open-source database, 1 from a previous project)
4. ***Develop and publish*** a "black box" version of the analysis code that will be usable by site surveyors, device developers etc. without specific academic expertise in the methods applied
5. ***Investigate*** turbulence production by waves and mean currents at the test site of SO1.

3 Work carried out

In the early stages of the WTIMTS project, the project support enabled the completion of a paper on the use of the statistical-only empirical-orthogonal function (EOF) method to decouple waves and turbulence [6]. This paper showed that at a site with strong wave action, the statistical method could identify a statistical mode in the calculated TKE field that is strongly correlated with wave action, as shown in Figure 1.

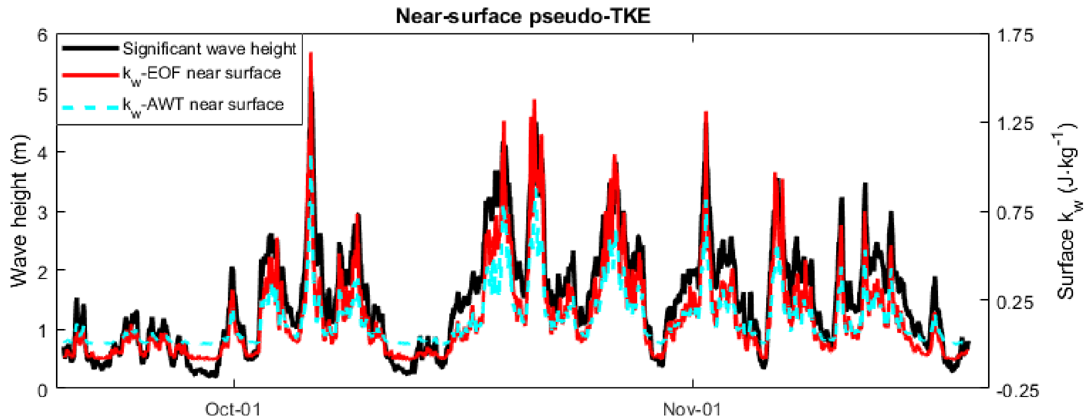

Figure 1: Significant wave height and two estimates of wave-related pseudo-TKE (k_w) from EOF analysis and Airy wave theory (AWT) across two months of data from a site off the northwest of Anglesey.

This paper also included a preliminary exploration of extending the statistical method to use more than one mode to capture the wave pseudo-TKE k_w, which is an important consideration in adapting the statistical and spectral-statistical methods to application in data from different sites.

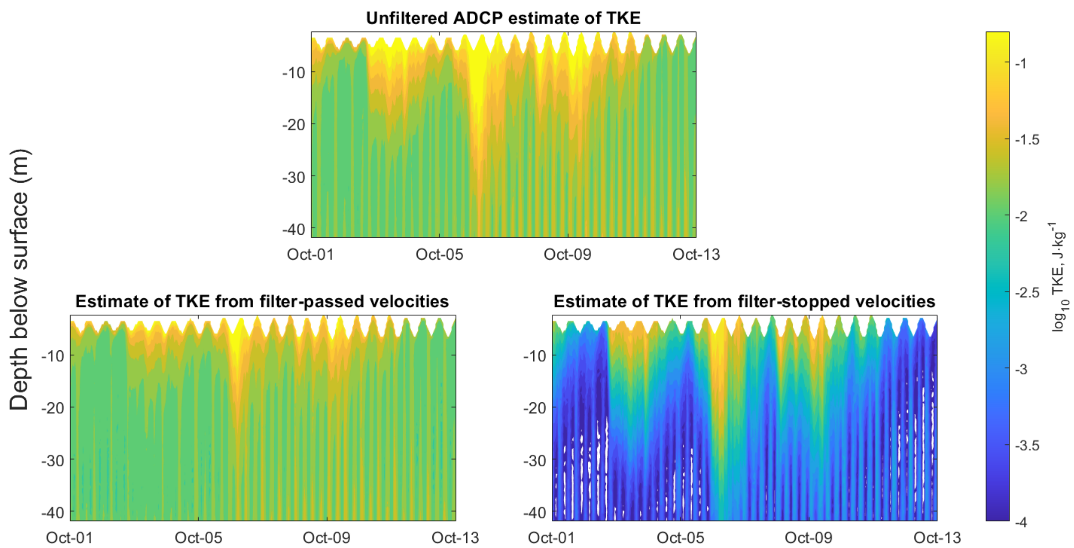

Figure 2: Upper panel shows estimate of TKE from unfiltered ADCP velocity measurements; lower panels show TKE calculated from velocity time series passed and stopped by a spectral filter.

Following the successful application of the statistical filter, the next step was to consider the integration of the spectral filter (also referred to as the wavelet synchrosqueezed transform, or WSST, filter) alongside it. As mentioned above, the spectral filter is used directly with the beam velocity time series recorded by the ADCP, and so it can be applied immediately following the data quality control. Preliminary studies with the spectral filter found that it was able to isolate a portion of k_w, but that a significant fraction of k_w remained coupled with the true TKE, as can be seen in Figure 2. This led to reframing the outputs of the spectral filter: rather than regarding them as "turbulent" and "wave" components of the estimated TKE, they were referred to as "filter-passed" and "filter-stopped". In this framework, the "filter-stopped" velocity time series contain only activity related to wave action, but not all of it. The "filter-passed" velocity time series contain all the turbulent activity, but a remainder of the wave activity is still present.

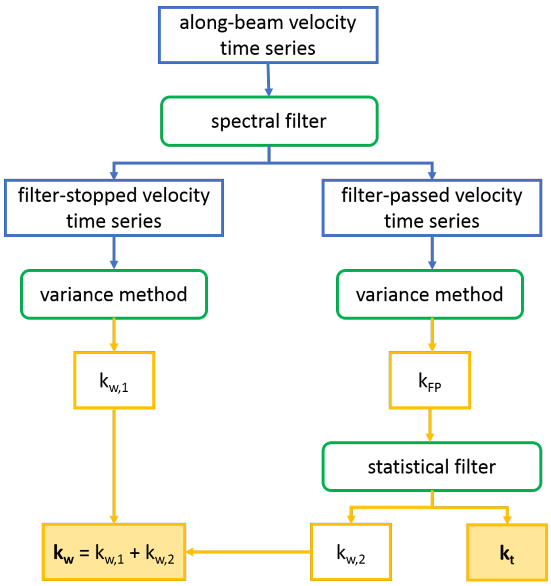

Figure 3: Flowchart showing relationship between spectral and statistical filters in combined method

This realisation led to the development of the double filter approach that is shown in the schematic in Figure 3. With this approach, the spectral filter is used to separate the velocities into filter-passed and filter-stopped components as described in the previous paragraph. Part of the wave pseudo-TKE is then calculated from the filter-stopped velocities; this is denoted $k_{w,1}$. The filter-passed velocities are similarly used to calculate a TKE field containing both the true TKE and the remaining wave pseudo-TKE; this is called k_{FP}. The statistical filter is then applied to the kFP to get the final estimate of the true TKE (k_t) and the remaining portion of the wave pseudo-TKE ($k_{w,2}$). Finally, $k_{w,1}$ and $k_{w,2}$ are summed to get the final estimate of the total wave pseudo-TKE (k_w).

The effectiveness of this method when applied to a decomposition of the wave and turbulence contribution to TKE estimates from ADCP measurements in the West Anglesey demonstration zone (WADZ) has been tested. These measurements are particularly useful because alongside the ADCP, a wave buoy was also deployed simultaneously; this allows an independent estimate of the wave properties and therefore tests how well the method performs.

In the first implementation of the model, it was observed that, in practice, the filter-stopped velocities from the spectral filter did not contain only wave-associated motions as intended. This is visible in the bottom right panel of Figure 2: although periods of strong wave activity are clearly captured as patches of high-magnitude pseudo-TKE near the surface if TKE is calculated from the filter-stopped velocities, nearer the bed a semi-diurnal pattern of stronger and weaker pseudo-TKE is noticeable. It is evident that this semi-diurnal feature must be related to tides rather than to wave activity, and therefore should not be present in the filter-stopped TKE estimate. To overcome this difficulty, the filter was revised so that it would be applied more selectively. In particular, the filter was changed to only be applied if the spectral peak exceeds a certain minimum magnitude. Remembering that the TKE values indicated by the contours in Figure 2 are expressed in a logarithmic scale, the peak values in the near-bed semi-diurnal feature and the near-surface wave-associated features are separated by 1-2 orders

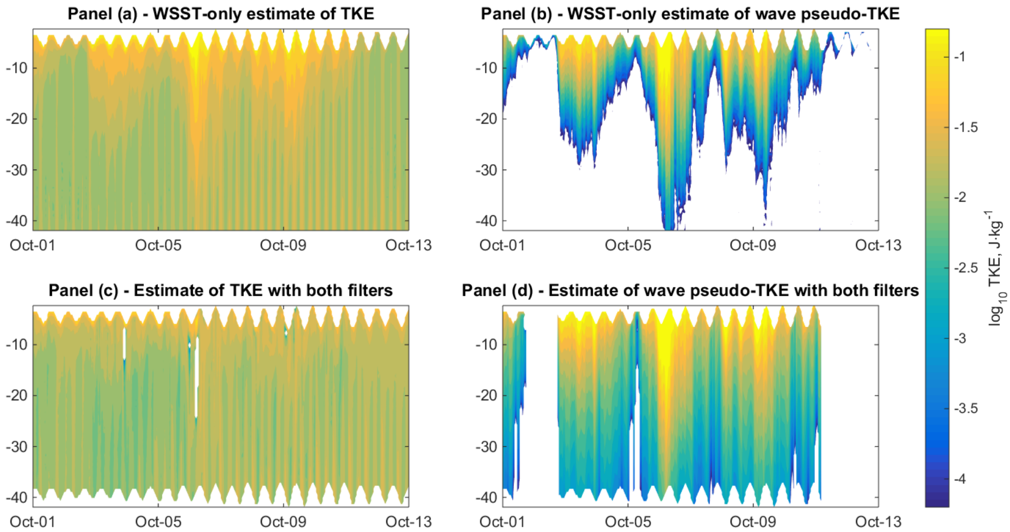

Figure 4: Upper panel shows estimates of TKE from spectral filter-passed (panel a) and filter-stopped (panel b) velocity records; lower panels show estimates of k_t (panel c) and k_w (panel d) after application of both filters.

of magnitude. This gives significant leeway to specify a minimum spectral peak magnitude for which the filter can be applied without defining the value precisely. This adjustment to the spectral filter resulted in a far better separation of waves and turbulence, as can be seen by comparing panel (b) of Figure 4 with the lower-right panel of Figure 2.

Figure 4 also shows typical results for the separation of waves and turbulence achieved with the double filter in panels (c) & (d). The nature of modes in an EOF decomposition mean that the double-filtered estimates of k_w persist to the bed at almost all times when wave activity is detected near the surface; however, the semi-diurnal signal is no longer evident giving confidence that this is not

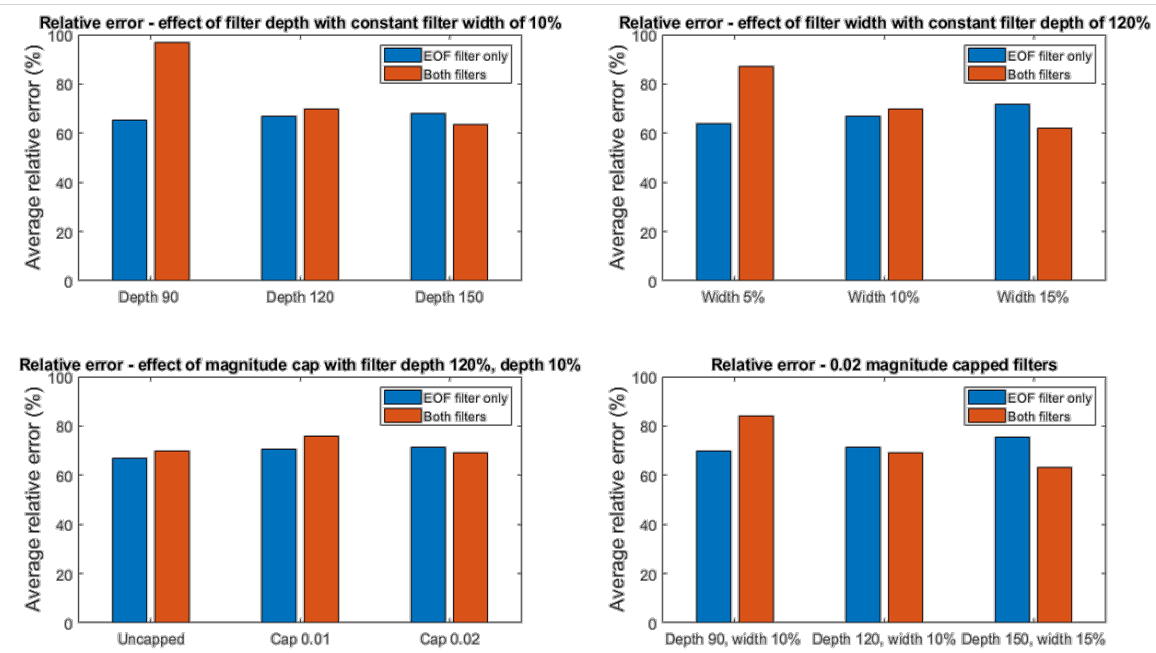

Figure 5: Upper panel shows estimates of TKE from spectral filter-passed (panel a) and filter-stopped (panel b) velocity records; lower panels show estimates of k_t (panel c) and k_w (panel d) after application of both filters.

correlated with tidal action. The more satisfactory result is the k_t estimate, which has no visible persistent wave-associated features apart from a peak in the top bin.

As mentioned above, a wave buoy was also deployed at the WADZ site during the period in which the ADCP measurements were taken. These independent measurements of wave properties give a "baseline" wave pseudo-TKE k_w against which to assess the filter performance; specifically, by taking the buoy measurements of significant wave height and period (and converting from observed period to intrinsic period using the current measurements from the ADCP), a theoretical estimate of the wave pseudo-TKE based on linear wave theory is obtained. Using this as the point of comparison, it can be seen that the double-filter improves the estimate of k_w over what is obtained using the statistical filter alone – see the errors between the two methods of estimating k_w depicted in Figure 5. However, this improvement is only obtained with certain implementations of the spectral filter: in particular, more aggressive filters which stop a greater proportion of the spectral energy over a wider frequency range yield better results than filters with lower amplitudes and narrower bands. The magnitude of the improvement is no more than 15 percentage points reduction in error; a qualitative comparison of the k_t estimates between the single- and double-filter cases suggests that the improvement in the isolated turbulence component may be much better, but it is not possible to quantify this without a similar "baseline" estimate of the true turbulent TKE, which is not available. See Section 4 for a discussion of the ongoing work to address this gap.

Per the specific objectives set out at the start of WTIMTS, the code written to implement this filter has been made available on an open-source repository [7]. The same repository also includes a user's guide explaining the use and function of the code; this will enable the work of WTIMTS to be more easily built on in future research.

4 Ongoing work

The second specific objective of the WTIMTS project was to benchmark the double-filter method against virtual site data that is being developed in Supergen ORE's Hub WP2. In particular, the project plan foresaw using virtual metocean data of Task 2.1, which includes depth profiles and time series of both currents and turbulence, as an artificial flowfield that could be "sampled" in an ADCP-like fashion. This would allow the performance of the method to be benchmarked against more data. However, after discussions with Hub research staff after project start, it was determined that the resolution of the virtual metocean data is not suitable for use in this manner. Developing a virtual flowfield was not a plausible goal with the resources of the project; however, collaboration is now ongoing with the developers of an earlier virtual flowfield method [8] to test the method with a fully-specified turbulence and wave field, with the intention to publish a paper on the findings of this study.

The objective of applying the method at multiple sites was, in the project plan, tied to the production of a conference paper. Due to delays in the project start date, the planned conference paper was prepared earlier in the project lifetime than anticipated in the original plan in order to meet the timelines for the EWTEC 2021 conference. This change to the project timeline has meant that application of the method to new sites has not been as high a priority and although this work has begun, it is not fully yet documented. The two sites investigated were a berth in the EMEC tidal test centre in the Fall of Warness, and an older data set from Ramsey Sound in west Wales obtained in advance of Tidal Energy Ltd.'s deployment of their DeltaStream prototype. Preliminary analysis of the Fall of Warness data yielded similar observations to those from the analysis of the WADZ data set, although without an independent estimate of wave action it is not possible to quantify the performance of the filter in the same way. The Ramsey Sound data set also does not allow estimation of the filter error, but shows some interesting discrepancies from the other two sites. In particular, as the Ramsey Sound measurement location is in a narrow (ca. 1km wide) strait between the southwestern peninsula of Wales and Ramsey Island, it experiences much lower wave conditions. It appears that as a result the wave pseudo-TKE is captured by the second EOF mode rather than the first. This suggests that future development of the model should incorporate a check for 'wave-like' behaviour of the EOF modes (e.g., an approximately sinh-like decrease in amplitude with depth, as predicted by Airy wave theory) rather than simply assuming that the first EOF mode corresponds to wave action.

5 Funding opportunities to build on WTIMTS

The strongest candidate for a project bid to carry on the work of WTIMTS will be an EPSRC first investigator award to be submitted by Dr. Michael Togneri. The intended scope of the project will be to continue the development of turbulence measurement at tidal sites with Doppler instruments. This will involve:

- Concluding the virtual benchmarking of the method.
- Deployment of a novel converging-beam ADCP design alongside a conventional ADCP including use of a vertical beam for surface-tracking wave measurements
- Deployment of a forward-looking single-beam device on a mid-depth buoy to measure lengthscales and 1-D turbulence at several streamwise-separated locations

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