

# Update on EMEC activities, resource description, and characterisation of wave-induced velocities in a tidal flow.

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## Abstract

The European Marine Energy Centre (EMEC) has been established in the UK as an open-sea grid-connected test facility for wave and tidal devices. Developers receive detailed site information regarding the resource available, environmental characteristics, and meteorological data. There is a range of additional support, including assistance with legislation and consenting, as well as technical and operational matters.

Whilst being primarily an operational test centre serving individual device developers, there is additional scope at EMEC for investigation of a range of unknown issues which need to be addressed by the wave and tidal industries in general as they develop to commercial viability.

In addition to providing an update on the current situation at EMEC, this paper also discusses some of the work being undertaken at the centre on data provision and interpretation, in particular regard to the tidal test site.

For its tidal test site, EMEC is currently developing Acoustic Doppler Current Profiler (ADCP) survey methodologies in order to address developers' needs for an appropriate picture of the raw energy. The tidal flow is not homogeneous. It is therefore necessary to capture wave-induced velocities which can be particularly important during high sea states and turbulence, especially within the seabed boundary layer. Progress in this ongoing work is also presented.

**Keywords:** Energy, Tidal, Wave-current interactions, Environmental impacts.

## Nomenclature

$H_{m0}$  = significant wave height  
 $P$  = wave penetration  
 $mCD$  = metre relatively to Chart Datum  
 $R$  = correlation coefficient

### Subscripts

max = maximum value  
mean = mean value  
 $t$  = time

## 1. Introduction

EMEC is a test centre created to promote the development of the wave and tidal stream energy conversion industries in the UK and wider. It has been established as a private company, overseen by a Board of Directors. Its staff includes the Managing Director, Operations team, Research, Data and Consents team, Office Administrator, and Business Development Officer.

With increasing emphasis on the role of renewable energy sources within future energy policy, both nationally and internationally, the test centre has been established using public funds from a variety of sources across Scotland and the UK, including some European funding for the tidal test site.

EMEC was initially proposed at the turn of the millennium, at which time it was recognised that the wave and tidal energy industries would benefit from the provision of essential infrastructure, including grid-connection, to allow a 'plug and play' approach to testing. This was in part due to the high cost of all marine works, including subsea cabling.

The provision of existing cable connection and other facilities spreads the financial and effort requirements between developers at this crucial stage of development of these industries. Since testing at EMEC is for relatively short periods, the time and expense involved in subsea cabling and grid connection would be likely to prove prohibitive to smaller companies seeking to test prototypes at pre-commercial stages.

Also recognised was the importance of providing test berths in real open-sea conditions, with good wave and tidal resources. This would enable developers to progress with pre-commercial testing of devices in resources that were typical of those they would encounter during fully commercial deployments.

The decision to locate this facility in Orkney recognised the excellent wave and tidal resources, together with a number of other benefits, such as proximity of the test sites to an existing UK grid connection point, and the wide range of expertise and marine services available locally.

In addition to the UK grid connection via cables laid on the seabed, EMEC offers a range of facilities and support services to wave and tidal device developers, which are summarised as 'hard' and 'soft' provisions in section 2.

## 2. Hard Provisions – Infrastructure

### 2.1 Wave Site

The EMEC wave test site is located off the west coast of Mainland Orkney, 2km off Billia Croo bay. There are currently four test berths located in water depths of approximately 50m, with a possible fifth that may provide future grid connection in shallower water.

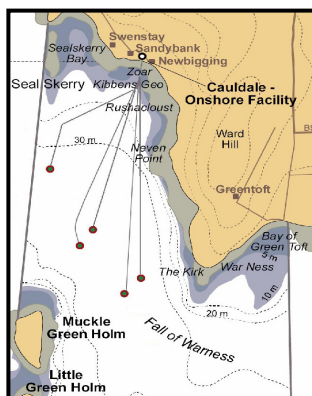
The existing four cables connect the substation which lies just above the beach at Billia Croo to the centres of the test berths. Cables are protected through the surf zone by custom-built armouring.



**Figure 1:** Location of the EMEC wave facility, off Mainland Orkney. [1]

### 2.2 Tidal Site

The EMEC tidal test site is located to the west of Eday, one of Orkney's North Isles, and east of Muckle Green Holm, in a tidal stream known as the Fall of Warness. This body of water is approximately 2km wide and 3.5km long. There are currently five test berths located in water depths of approximately 25-50m. The cables run from the substation which lies just above the beach at Caldale, through the beach, and along the seabed, terminating at the berth positions.



**Figure 2:** Location of the EMEC Tidal Test Facility, off Eday. [1]

### 2.3 Electrical Provision

The electrical provision at the EMEC wave facility at Billia Croo is similar (but not identical) to that at the tidal site. Seabed cables at the wave berths feed into the UK grid via an 11kV, 50Hz connection to the Distribution Network Operator's substation at Stromness. The wave site has a registered capacity of 7MW. The substation at Billia Croo houses incoming metering circuit breakers (CBs), four test berths CBs and the Power Factor Correction CB. Each test berth breaker has the facility to isolate and earth the subsea cable for that berth.

Test berths carry separate relays, providing overcurrent and earth fault protection, and have a facility for pilot-wire trip from the devices. Further protection functions can be implemented as required.

Power factor correction (PFC) is provided if required. The PFC capacity is shared amongst the four test berths and developers have a proportional entitlement of one quarter of the capacity per cable.

The cables were custom-built for EMEC, and include fibre-optic bundles for data transmission.

## 3. Soft Provisions – Support and Services

### 3.1 Power Purchase and Validation

In addition to the physical connection to the UK grid, developers deploying at EMEC benefit from a range of other provisions. By deploying at EMEC, developers buy into the existing Power Purchase Agreement established by the company, and they claim their full payments for power produced by their own device, under the Renewables Obligation Certificate (ROC) system.

The independent validation of generation performance during testing is one of the services provided by EMEC. This is one of the key issues for developers wishing to attract investment for commercial development beyond the testing stages at EMEC.

### 3.2 Wave, Tidal and Meteorological Data

#### Wave Site Data

A number of surveys and studies have been undertaken at the Billia Croo wave site since its inception in 2001. These include hydrographic and current surveys as well as wave climate studies at different depths. Wave rider buoy data has been collected since late 2001, and is ongoing. This data is issued each month to developers looking to deploy for testing at EMEC. Wave and meteorological data for the wave site is analysed and a monthly summary report is prepared. This report has been developed by the International Centre for Island Technology (ICIT) – the local branch of Heriot Watt University – with input from EMEC staff. These reports are also available to developers.

#### Tidal Site Data

Similar surveys have been undertaken at the tidal site, the development of which began in 2004. These also include a number of hydrographic reports, and several current surveys which have been undertaken at various

locations around the site, including the actual berths. In addition, a study of the wave climate at the tidal site was undertaken in 2006, and various *in situ* wave data sets have been gathered from the ADCP deployments.

**Meteorological Data**

Meteorological data has been collected at Billia Croo since May 2004 and includes wind speed and direction, air pressure, temperature and rainfall. The same is planned for the tidal site, which became operational in late 2006 but, in the meantime, data from Billia Croo or the Orkney Islands Council can be used.

**Environmental Characterisation and Device Licensing**

Before being established, each of the test sites was subject to an Environmental Impact Assessment (EIA) which accompanied the licence applications for the infrastructure. These assessments covered both the specific laying of cables and all associated land works involved with the construction of the substation buildings. They also included some consideration of the range of effects that might be expected as a result of the types of devices likely to be deployed in the future.

Developers seeking to deploy their devices at EMEC are required to produce an assessment of the possible environmental effects of their device on the receiving environment, which emphasises the relatively small scale of activities. They also need to produce full safety documentation, and liaise with EMEC staff to ensure dovetailing between their own and EMEC’s working practices. Developers undertaking this process have access to the relevant site EIA, which describes the receiving environment, and other EMEC data and information. They are also given detailed guidance [2] and assistance from EMEC staff, who have established good relations with the regulatory bodies and stakeholders with whom they consult. The documentation produced is submitted by EMEC, on behalf of the developer, to the relevant regulatory authorities for licensing the proposed deployment.

**Full Time Emergency Response Cover**

EMEC operates a 24/7 emergency response Duty Manager system. Whilst emergencies involving devices are the full responsibility of the developer and any contractor they employ, the EMEC emergency response system ensures that developers are aware of any incident and are taking appropriate action.

**Local Offices with Real-time Device Data**

Each developer is offered a self-contained secure office at the EMEC offices in Stromness. Data from each device is transmitted from the substation at the shoreline of each test site, via fibre optic cables located within the developer-specific cables, into the developers’ individual offices. Developers therefore have secure areas for both office space and data storage. EMEC has non-disclosure agreements with all developers and ensures that all commercially sensitive information is securely located.

**Links to Local Expertise**

Orkney has a range of expertise relevant to the marine energy industries. There is a variety of work boats and tugs available for hire, as well as construction and engineering companies, electrical contractors, a branch of Heriot Watt University, and several environmental consultants offering a range of services. There is a great wealth of experience of local waters, and wide public support for the development of wave and tidal energy conversion devices. EMEC tries to encourage the use of local expertise wherever possible, and can offer developers good contacts across many areas.

**4. Wave and Tidal Resources at EMEC**

**4.1 The Wave Resource at EMEC**

The Billia Croo wave site experiences the full Atlantic fetch, with incoming waves predominantly from the NW. Table 1 shows some of the average and extreme data from the site.

Typical Averages	
Significant Wave Height (m)	1.9
Zero Up-Crossing Period (s)	5.9
Mean Direction (° True North)	291
Power (kW/m)	22.1

Extremes				
Return Period (years)	1	10	50	100
Significant Wave Height (m)	10.0	12.7	14.7	15.4
Zero Up-Crossing Period (s)	11.7	13.2	14.2	14.6
Mean Direction (° True North)	285	284	284	284

**Table 1:** Average and Extreme values at Billia Croo.

As Table 1 shows, the site experiences an average power estimated at 22kW/m and an average significant wave height of 1.9m. This table also shows a 100-year extreme significant wave height of 15.4m, with a 100-year extreme zero-upcrossing period of 14.6s. There is ongoing analysis of a number of aspects of the Billia Croo wave data, including a comparison of the data from wave rider buoys at different locations. These studies will be reported in due course, once completed.

**4.2 The Tidal Resource at EMEC**

The EMEC tidal site experiences very strong tidal streams in both NW and SE directions, through the Fall of Warness. This is mainly due to the narrow channel between the island of Eday and Muckle Green Holm. Spring tides are around 7kn (3.5m/s) on the SE-going stream and 6.5kn (3.34m/s) on the NW-going stream. For

the neap tides, the typical strengths are in the order of 2.8kn (1.44m/s) and 2.5kn (1.29m/s) respectively.

## 5. High-Frequency ADCP survey

### 5.1 Survey

The development of marine current energy converters (MCEC) requires an appropriate picture of the raw energy targeted. Marine currents are not homogeneous. It is therefore necessary to capture turbulence (eddies and bottom boundary layer - BBL) and wave-induced particle velocities. The latter can be particularly important during high sea states.

For the Fall of Warness, EMEC is currently developing Acoustic Doppler Current Profiler (ADCP) survey methodologies in order to answer this need. The measurements are undertaken with high vertical and temporal resolutions (around 1m and 1s) during a period long enough to include a wide range of sea states and allow a harmonic analysis (around a winter month).

This section deals with the first high vertical and temporal resolutions survey that was undertaken at the Fall of Warness. The instrument used was a Teledyne RDI, Workhorse Sentinel 600kHz ADCP in High Rate Pinging Mode 12. Table 2 gives the specifications of the survey.

Instrument	RDI Workhorse Sentinel ADCP
Acoustic frequency [kHz]	600
Pinging Mode	High Rate Pinging Mode 12
Time/Ping [s]	1
Time/Ensemble [s]	1
Pings/Ensemble	1 (single ping)
Duration [days]	5
Water Depth [mCD]	45
Depth cells number [bins]	45
Depth cell size [m]	1
Height of instrument over seabed [m]	1
Referential coordinates	Beam coordinates

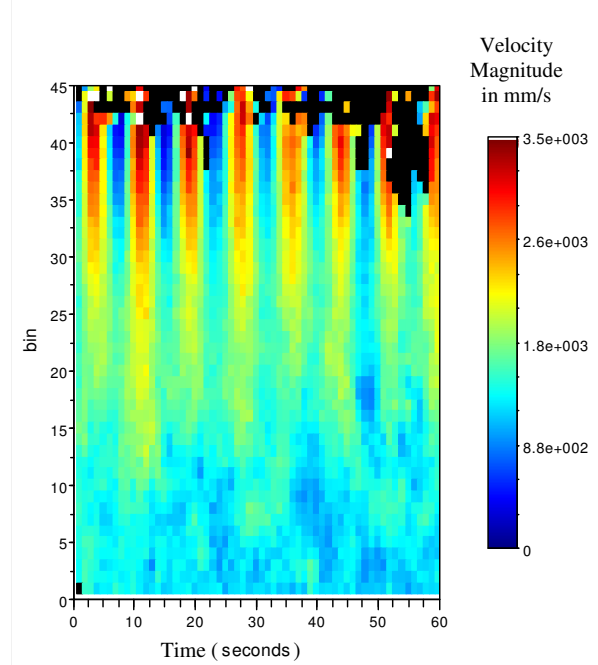
**Table 2:** ADCP survey specifications.



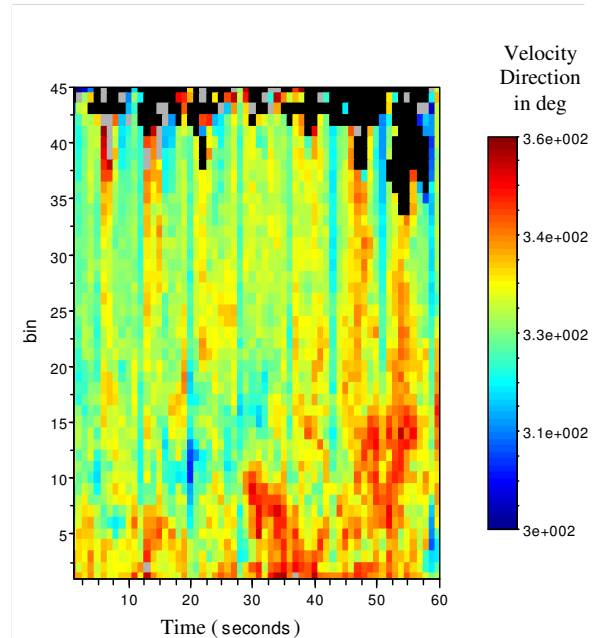
**Figure 3:** The instrument in its frame before deployment.

The velocities were saved in beam coordinates. Due to the early stage of the survey, only one battery pack was used and the survey lasted only 5 days. The instrument deployed in its frame was located 1m above the seabed (see Figure 3).

### 5.2 Velocity Analysis



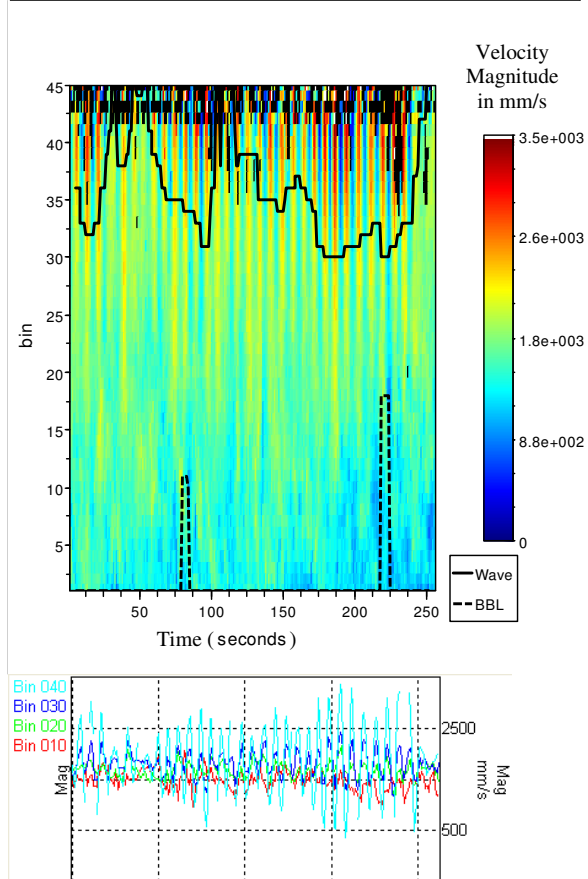
**Figure 4:** 1minute subset: velocity magnitude (mm/s).



**Figure 5:** 1minute subset: velocity direction (deg).

Once the instrument was recovered, the binary data was processed using RDI software WinADCP in order to output velocity magnitude and direction time series in Earth Coordinates. Throughout the survey, both BBL turbulence and wave-induced particle velocities appear in the data (see Figures 4 and 5 for a 1minute example). The direction does not significantly change (it stays between 300 deg and 10 deg for the NW-going flow). A visual check of this relative monotony was undertaken for the whole survey and proved that it was relevant to study the magnitude only for this work. For further analysis, it is recommended to study the projection of the velocity vector against the main direction of the tidal ellipse of the site.

Comparing different subsets, the requirement for a ‘turbulence penetration parameter’ was raised in order to characterise how deep (high) the wave-induced velocities (BBL turbulence) penetrate the water column. The chosen parameter was defined for the wave penetration as: the deepest bin at which the difference between the maximum and minimum velocity magnitude exceeds 1m/s within a centred 10s sample (scanning period). This parameter was produced every second and limited to mid-depth. In reality, wave-induced velocities can impact further down the water column, but this limitation was required as a first attempt to artificially separate wave-induced velocities and BBL turbulence.

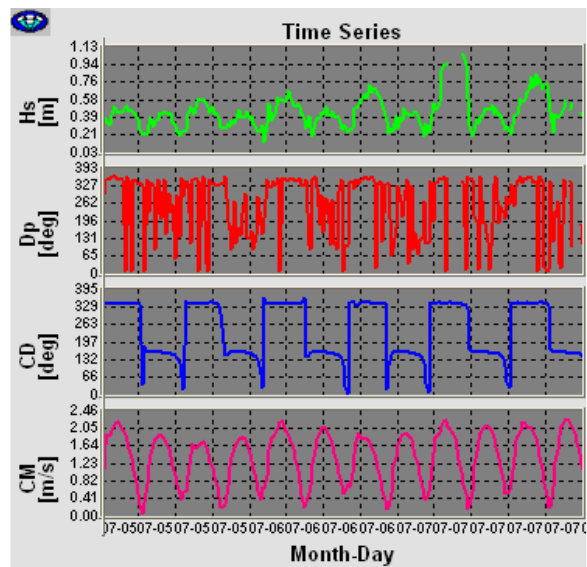


**Figure 6:** 4minute subset: velocity magnitude (mm/s) with  $H_{m0} > 1m$  (corresponding 20 minute subset).

A similar parameter was derived for the BBL penetration, but upwards instead of downwards. Figure 6 shows the results of the analysis for a 4minute sample which contains the previously mentioned 1minute sample. This shows that the waves ‘penetrate’ as far down as the 30<sup>th</sup> bin (around 15m depth) and the BBL ‘penetrates’ as far up as the 17<sup>th</sup> bin (around 28m depth). This leaves a ‘non-penetrated’ section of only 13m in the middle of the water column.

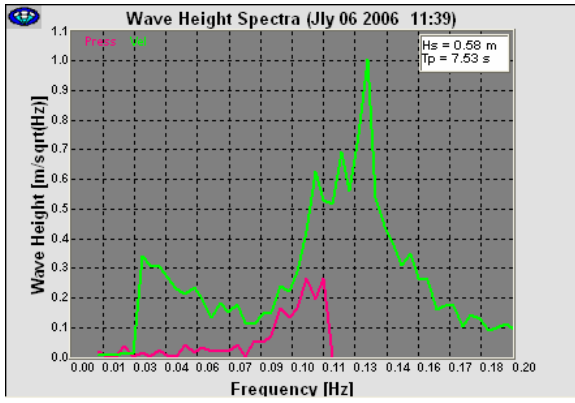
### 5.3 Waves Analysis

The RDI WavesMon software was used for the wave analysis. It usually inputs beam coordinates velocity data at 2Hz in order to compute the wave spectra. For this survey, the velocity was sampled at 1Hz and therefore an ad-hoc processing was required through WavesMon. This was undertaken by Loïc Michel at Teledyne France RDI Instrument Europe. A section of the results is shown in Figure 7.



**Figure 7:** Time series of significant wave height, wave peak direction, current mean direction and current mean magnitude.

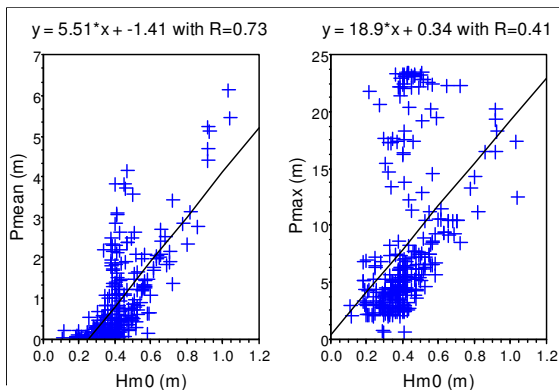
The results show expected patterns such as the significant wave height (noted  $H_{m0}$  or  $H_s$  in some figures) to be larger when the current faces the waves [3] (here the wave direction is the direction from where the waves come. The current direction is the direction to where the current vector points). However, Figure 8 shows that the two spectra available from pressure and velocity measurements are not in agreement. It was not possible to retrieve the third spectrum from the surface tracking measurement probably due to the insufficient range of the instrument. Since the velocity spectra are not validated against the pressure and surface tracking spectra, it is not possible to demonstrate the integrity of the  $H_{m0}$  data which were derived from the velocity spectra.



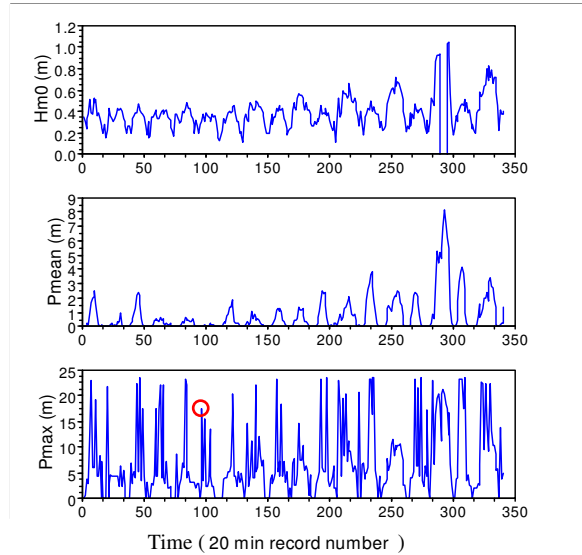
**Figure 8:** 20minute spectra from the pressure measurement (pink-low curve) and from the velocity measurements (green-high curve).

#### 5.4 Correlation

Although the spectral results are not quantitatively reliable, it was proposed to qualitatively correlate  $H_{m0}$  with the wave penetrations. The wave penetration depth was derived from the wave penetration bin, taking into account the water depth measured by the pressure sensor (corrected for the 1m offset at the seabed). The mean ( $P_{mean}$ ) and max ( $P_{max}$ ) of the wave penetration depths were taken over the 20minute intervals that matched the spectral analysis. Figures 9 and 10 show the correlation of  $H_{m0}$  with  $P_{mean}$  and  $P_{max}$ , with respective correlation coefficients of 0.73 and 0.41.

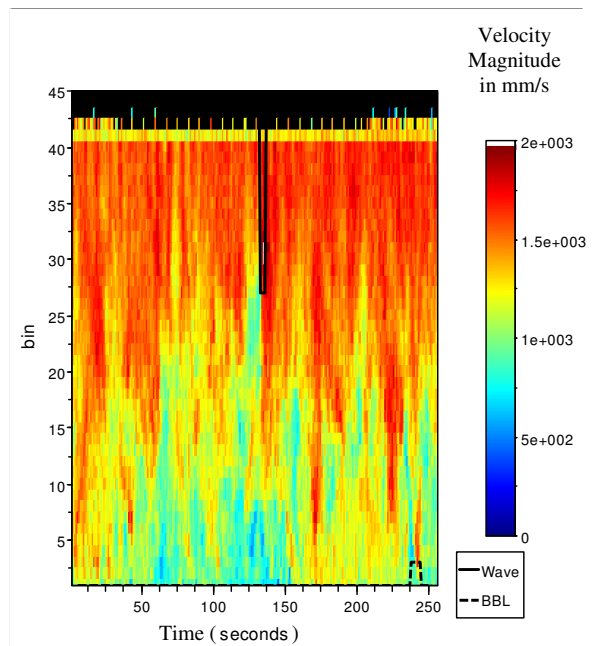


**Figure 9:** Correlation graphs for  $P_{mean}$  and  $P_{max}$  against  $H_{m0}$ .



**Figure 10:** Time series of  $H_{m0}$ ,  $P_{mean}$  and  $P_{max}$ .

Figure 9 shows outliers, especially for the  $H_{m0}/P_{max}$  correlation. Looking at the 4minute records when these outliers happen, it appears that they are due to turbulence (from BBL or eddies) occurring in the top half of the water column. Figure 11 shows a 4minute record with a corresponding 20minute  $H_{m0} = 0.3m$  and  $P_{max} = 18m$  (see red circle on Figure 10). There is no apparent wave-induced velocity and the penetration bin stays at bin 45. However some obvious turbulence can be seen with one particular turbulent event occurring in the top half of the water column, creating an outlier  $P_{max}$  of 18m.



**Figure 11:** Wave  $P_{max}$  induced by turbulence.

### 5.5 Conclusion and Future Prospects of the ADCP measurements.

The velocity data from this high frequency survey proved to be of good quality and showed both wave-induced particle velocities and turbulence. Although the wave data was unreliable and the definition of the penetration parameters has not been validated, the correlation showed promising results of wave-induced velocities penetration characterisation.

Improved turbulence characterisations using already defined parameters (such as Root Mean Square –RMS-turbulent fluctuations, Turbulent Kinetic Energy –TKE- and Reynolds stress [4-5]) would benefit the assessment of the turbulence in tidal sites exposed to waves.

In the near future EMEC is also planning to operate real time ADCP measurements that will improve the sampling frequency, the vertical resolution and the duration of survey. Improved wave spectra (with surface tracking and processing from 2Hz data) will also be generated.

Coupled with wave climate studies, such ADCP data could be replayed into numerical models of MCEC which could be of benefit to developers, facilitating improvement of device design.

Such ADCP data could also greatly contribute to the research on high-frequency turbulence and wave-current interactions, for which little in-situ data have been collected to date. Currently, Ian Bryden (University of Edinburgh) and Ruairi MacIver (University College of Cork) are undertaking research on EMEC's ADCP data.

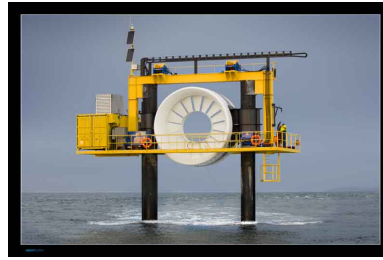
## 6. Uptake of EMEC Facilities

Since the wave site was officially opened in August 2004, Billia Croo has seen the deployment of the *Pelamis* device, developed by Ocean Power Delivery (OPD), which has successfully generated electricity into the UK grid.

At the tidal site, Open Hydro's 1/3 scale open-centre turbine has already been successfully installed in a depth of 18m, with grid connection imminent at the time of writing. Figures 12 and 13 show, respectively, *Pelamis* on its way to Billia Croo and Open Hydro's device installed at the Fall of Warness tidal site.



**Figure 12:** OPD's *Pelamis* on its way to the EMEC wave site at Billia Croo



**Figure 13:** Open Hydro's open centre turbine installed at the EMEC tidal site at the Fall of Warness.

A number of developers are also planning to deploy at EMEC, both at the wave and the tidal sites. In shallow waters at Billia Croo bay, EMEC has already been able to assist in mechanical testing of a device for a company from Finland. Whilst this test device was not grid-connected, the device was successfully installed and pressure measurements were able to be taken, which indicated the level of performance.

More recently, a number of wave developers have come forward, planning to deploy at EMEC over the next two years and some are already well advanced in the licensing stages.

Several other developers are also planning to deploy a range of tidal devices at the tidal site over the next few years, with some already moving ahead to the licensing stage.

## 7. Investigation of Unknowns

Developers wishing to deploy devices at EMEC are required to obtain consents in relation to their particular device. With licensing regulators and their statutory consultees required to adopt a precautionary approach to unknown potential impacts, there is the potential for the existence of such unknowns to hinder the whole development of the wave and tidal energy industries.

Adopting a precautionary approach means that the potential for impacts on specific site sensitivities must be addressed by developers in the ES, in a way considered acceptable by the regulatory bodies and consultees of the licensing process. Indeed, consultees of the consents process are required under European legislation to pay particular consideration to the potential impacts on protected species, with increasing emphasis on the Precautionary Principle. To ease this process, EMEC has been involved in discussions with the main bodies, to find a way to avoid long delays to device deployment at this crucial test stage.

The key to a solution has been to accept that responsible monitoring needs to be put in place, which will serve to provide reliable scientific data and thereby enable a more objective assessment of the risk. EMEC has been developing a monitoring plan, which addresses the particular sensitivities of its test sites and has been working to ascertain the best monitoring methods that should be used by developers testing at its facilities. Some of these monitoring measures are already in place. By cooperating

with these plans and methods, developers can gain essential information about the interactions of their own device with the receiving environment. Such knowledge will be crucial: to developers, as they progress to fully commercial deployments after testing at EMEC; to regulators, who will then be better able to make informed decisions relating to future licensing of devices; and to the wave and tidal industries as a whole, which will accumulate scientifically robust data on the effects of these industries as they develop.

By initiating the relevant crucial base data acquisition and ensuring that data collection continues until conclusive scientific information is obtained, EMEC can help facilitate a solution to the problems of unknowns.

## 8. The Future for EMEC

This is an exciting time for EMEC and device developers, with the next few years set to be very busy, as developers reach the reality of open sea deployments. Key to EMEC's success will be providing the necessary facilities and services to enable developers to be able to deploy their devices safely and in a manner which protects the receiving environment. With recognition of climate change increasing, the call for renewable energy sources has never been greater and EMEC is set to do all it can to facilitate the timely development of the wave and tidal energy industries, from pre-commercial to fully commercial stages.

## Acknowledgements

The second author acknowledges the support of Loïc Michel at Teledyne France R.D. Instrument Europe who produced the wave data; Ian Bryden (University of Edinburgh and one of the EMEC Board of Directors); and Ruairi MacIver (HMRC, University College of Cork), who shared helpful discussions on the data.

## References

- [1] © Crown Copyright and/or database rights. Reproduced by permission of the Controller of Her Majesty's Stationary Office and the UK Hydrographic Office ([www.ukho.gov.uk](http://www.ukho.gov.uk)).
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