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ReDAPT MD3.4

Interim Report: Turbulence Measurement and Characterisation

Revision 1.0

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Glossary

ADCP Acoustic Doppler Current Profiler.

ADP Acoustic Doppler Profilers (of which ADCP, AWAC and AQD are variants).

AQD I / II Aquadopp I / Aquadopp II.

Coordinates (Desc.) X = Longitudinal. Y = Transverse. Z = Vertical. See figure 1..

Depth profile A description of parameter variation along a vertical column.

EDF EDF Energy.

EMEC European Marine Energy Centre.

ETI Energy Technologies Institute.

Far Distance from the rotor > 2D or 30m.

GLGH Germanischer Lloyd Garrad Hassan.

High-Q High quality instrument data (according to EMEC SOP).

Horizontal Plane A description of parameter variation across both streamwise and spanwise directions.

Incident In the plane of the rotor.

Inflow In the plane of the rotor.

Low-Q Low quality instrument data (according to EMEC SOP).

Medium-Q Medium quality instrument data (according to EMEC SOP).

Near Distance from the rotor < 2RD or 30m.

Online Available for control and acquisition from shore.

Origin Centre point of turbine foundation [59°8’12.66”N 2°48’20.7”W] (18m from seabed TBC).

PDF Probability Density Function. A function that describes the relative likelihood for a random variable to take on a given value..

RD Rotor diameter.

ReDAPT Reliable Data Acquisition for Tidal.

SoP Standard Operating Procedure.

TGL Tidal Generation Limited.

UoE University of Edinburgh.

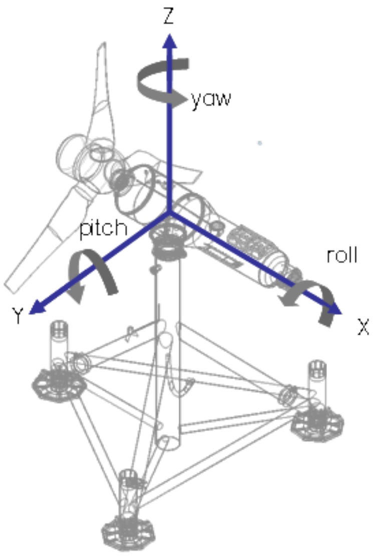


Figure 1: Coordinate system used in ReDAPT field measurement and analysis

Nomenclature

ϵ	Turbulent Dissipation Rate [m^2/s^3]
η	Surface elevation [m]
λ	Integral Length scale [m]
Φ	Roll [°]
Ψ	Yaw [°]
Θ	Pitch [°]
$D(z,r)$	Spatial structure function [m^2/s^2]
f	Frequency [Hz]
f_s	Sample Frequency [Hz]
H_{m0}	Significant wave height. Spectral wave parameter. [m]
H_m	Mean wave height. Time series zero crossing method. [m]
I	Turbulence Intensity [%]
R_D	Rotor Diameter [m] (500kW=16m tbc 1MW=16m tbc)
$S(f)$	Wave spectral density [$m^2.s$]
$S(f,\theta)$	Directional wave spectral density [$m^2.s.rad1$]

$S_t(f)$ Spectral Density (turbulence) [$m^2/s^2/Hz$]

T_p Peak wave period. [s]. Spectral wave parameter and approximate to Tm (mean wave period) from time series analysis.

TKE Turbulent Kinetic Energy [m^2/s^2]

u Streamwise velocity [m/s]

u' Streamwise velocity fluctuations [m/s]

U, V, W Mean velocity in x,y,z directions [m/s]

v Transverse velocity [m/s]

v' Transverse velocity fluctuations [m/s]

w Vertical velocity [m/s]

w' Vertical velocity fluctuation [m/s]

x Streamwise distance from origin [m]

y Transverse distance from origin [m]

z Vertical distance from origin (positive from seabed to surface) [m]

1 Objectives

This document relates to description of the statistics of turbulent flow fields, expressed in terms of a finite number of parameters, which can be either directly measured or derived through measurements. This description and characterisation is intended to help meet the goals of the ReDAPT project.

The objectives of the ReDAPT programme are to reduce costs in the tidal energy sector and to increase confidence in environmental parameter measurement.

The objective of the MD3 sub-project work package is to design and conduct a data acquisition campaign to increase understanding of the flow conditions in the nearfield of a tidal stream turbine and to increase confidence in flow measurement and analysis methods.

Deliverable MD3.4 has the following specific aims:

1. To introduce Numerical Modelling techniques used in the MD sub-project of ReDAPT.
2. To identify the fluid velocity measurement requirements of these Numerical Modelling activities.
3. To identify the extent to which these measurement requirements can be met within ReDAPT and to prioritise and schedule these measurements to best meet the needs of the project.
4. To identify and investigate potential strategies for the analysis of the acquired measurements with the aim of characterising turbulent flow.
5. To support the establishment of operational procedures for the acquisition of these measurements.

2 Flow Characterisation Methods

Flow characterisation of a tidal energy site centres on gaining information on water velocity over a range of spatial and temporal length scales suitably chosen to capture the key underlying fluid motions. These potentially include information varying across annual and seasonal time scales to fluctuations in velocity at timescales of seconds and below. Likewise, knowledge of spatial variation of flow parameters is required across a wide range, from orders of tens of blade diameters (for wake studies and array interaction for example) to variations of metres and below for investigations into blade fatigue. Ideally, 3D velocity information would be captured with high spatial densities of sub-metre resolution across the entire fluid domain of the turbine, at sample rates capable of measuring high frequency velocity fluctuations and for durations long enough to capture the characteristics of tidal cycles throughout the year. No instrument yet exists to provide these measurements. Identifying key velocity measurements and metrics that are obtainable, reliable and representative becomes the goal of any flow characterisation.

2.1 Flow characterisation within the Modelling Sub Project

Within ReDAPT, flow characterisation is being undertaken in the MD1, MD3, MD5 and MD6 workpackages. MD1 involves detailed and cutting-edge numerical simulation of the TGL 1MW tidal turbine in turbulent flows. MD3 involves measurement and analysis of field data local to the turbine and the design and validation of characterising parameters based on these measurements. MD5 involves the construction and validation of a model of the wider Fall of Warness, Orkney site through the incorporation of existing and planned field measurements. MD6 involves the validation - through comparison to field and machine data - of the GLGH Tidal Bladed software which seeks to capture environmental and turbine characteristics in a desktop application.

2.2 Numerical Simulation

Tidal flows are turbulent, exhibiting random motions across all dimensions. Whilst the equations to describe turbulent flows are known (the Navier-Stokes equations) the computational power required to model these flows across the entire scale of motion severely restricts a direct numerical approach (at present). Traditionally, extensive, expensive and careful experimentation has produced empirical formulae for simplified systems. As system complexity increases empirical methods become less realisable and/or reliable. In this regime, statistical methods can be applied to the Navier-Stokes equations to "smooth" the fluctuations (turbulence) whilst maintaining a correct description of the averaged properties such as velocity. The averaging of the turbulence terms cannot be fully neglected however. In order to maintain conservation of energy in the system, information on the characteristics of turbulent motion needs to be injected in to the numerical simulations. The descriptions of these motions and the methods of inputting the information into the simulations are called "turbulence models". These models simulate the effect of turbulence on the behaviour of the mean properties of the flow.

> "Turbulence models can only give an approximate description, and, with a particular set of empirical constants, they are valid only for a certain flow or at most a range of flows."

[1]

For reliable results consideration should be given to the following aspects of turbulence models:

- They need to be tailored for specific problems
- Their validity will likely be limited to specific types of flow or ranges of flows
- Extensive testing is required to have confidence in any extrapolations made
- Their associated computational expense increases with complexity

Parameter	Location	Data Required
Mean velocity:	U, V, W	e.g. U(t) at discrete z-ordinate
Turbulence intensity:	Ix, Iy, Iz	e.g. U(t) at discrete z-ordinate
Turbulence length scale:	Lx	Ux(t,x)(z) Synchronised measurements of U(t) at multiple x-ordinates for each z-ordinate.
	Ly	V(t,y)(z) Synchronised measurements of Uy(t) at multiple y-ordinates for each z-ordinate.
	Lz	W(t,z)(z) Synchronised measurements of Uz(t) at multiple z-ordinates at each z-ordinate.

Table 1: Identified preliminary velocity field parameters

In order to build confidence in a selected turbulence model and numerical simulation, verification with measurements in both the field and the laboratory may be required.

2.3 MD1 - Detailed Numerical Simulations

In order to increase confidence in the outputs of CFD techniques, confidence in the inputs to these numerical models must be established. CFD being conducted, as part of MD1 within ReDAPT, is based upon EDF's CodeSaturne [2]. This is an Open Source CFD code designed for efficient parallel computation of turbulent flow around and within complex geometries. The code includes a range of Reynolds Averaged Navier-Stokes (RANS) turbulence models and is widely used for Large Eddy Simulation (LES). The primary objective of the ReDAPT MD1 work is to compare numerical predictions of the characteristics of time varying load to measurements of time-varying loads on the TGL 1 MW turbine. It is crucial that the inflow conditions are defined such that the spatial and temporal variation of the incident flow are representative of the conditions experienced by the TGL turbine. Various parameters are employed to describe a turbulent flow (e.g. Table 1).

Turbulent length scales are of particular significance to the CFD work of MD1 which makes use of Large Eddy Simulation (LES). The software component that handles the generation of inflow data to these simulations, in this case the Synthetic Eddy Method (SEM), can use turbulence length scales to create velocity fluctuations that are more representative of the modelled environment [3]. Since the outputs of an LES model are known to be sensitive to inflow conditions, it is important that the ambient flow-field is accurately modelled so that physical and modelled effects can be isolated. The University of Edinburgh is working with EDF and their partners to ensure that values of important inflow parameters can be measured or inferred to an acceptable level of confidence. A preliminary specification can be found in tables 5 and 6.

2.4 MD6 - Industry Design Tools

The activities of MD6 aim to improve confidence in GLGH's Tidal Bladed tidal turbine design tool. Tidal Bladed, in order to give information on loads and performance of a particular tidal turbine, requires a description of the turbine (blades, rotor, drive train etc.) and a description of the environment (currents, waves, turbulence etc.). At present Tidal Bladed describes the environment in terms of vertical profiles of velocity and the turbulence intensity (from a prescribed location or "point") and seeks to incorporate the effects of waves through measurements of traditional wave spectral parameters such as H_{m0}. It is acknowledged, however, that, in the tidal energy field, not enough is known on the variability (both spatially and temporally) of these flow-describing parameters.

> Very few measurements of the turbulence intensity of tidal currents and their spectral distribution are known. Especially for the spectral distribution, no standard models as used in the wind industry or for sea state description [waves] exist. [4].

Unsteadiness in the flow, which imparts loads on to the tidal turbine, will be the result of both wave kinematics and turbulent fluctuations in the tidal stream. Unlike the wave-field, the tidal-flow-field does not have standardised parametric models which can be used to characterise it. Developing these models is one of the goals of MD3.

2.5 MD3 - Measurement, Analysis, Characterisation and Guidance

This task will extend knowledge of the nature of flow in energetic tidal sites and give guidance on suitable measurement methodologies. It will also establish techniques by which appropriate data can be generated in other candidate sites, especially as it might be expected that the most appropriate parametric description might be site specific, depending on, for example: bathymetry, mean flow speeds, topology, depth and fetch. The work includes consideration of stationarity, inhomogeneity and the need to adopt new instrumentation as it becomes available.

MD3.4 forms the first report on the theoretical and technical direction of the MD3 measurement campaign. [1] An update to this report will be submitted in January 2013 following UoE working experience of post-processing and analysing the near

[1] Summaries and presentations on marine operations and proposals for measurement configurations have previously been made available to the project partners and the ETI.

field data sets. A final report will be submitted in September 2013. See figure 2 for an MD3 reporting roadmap.

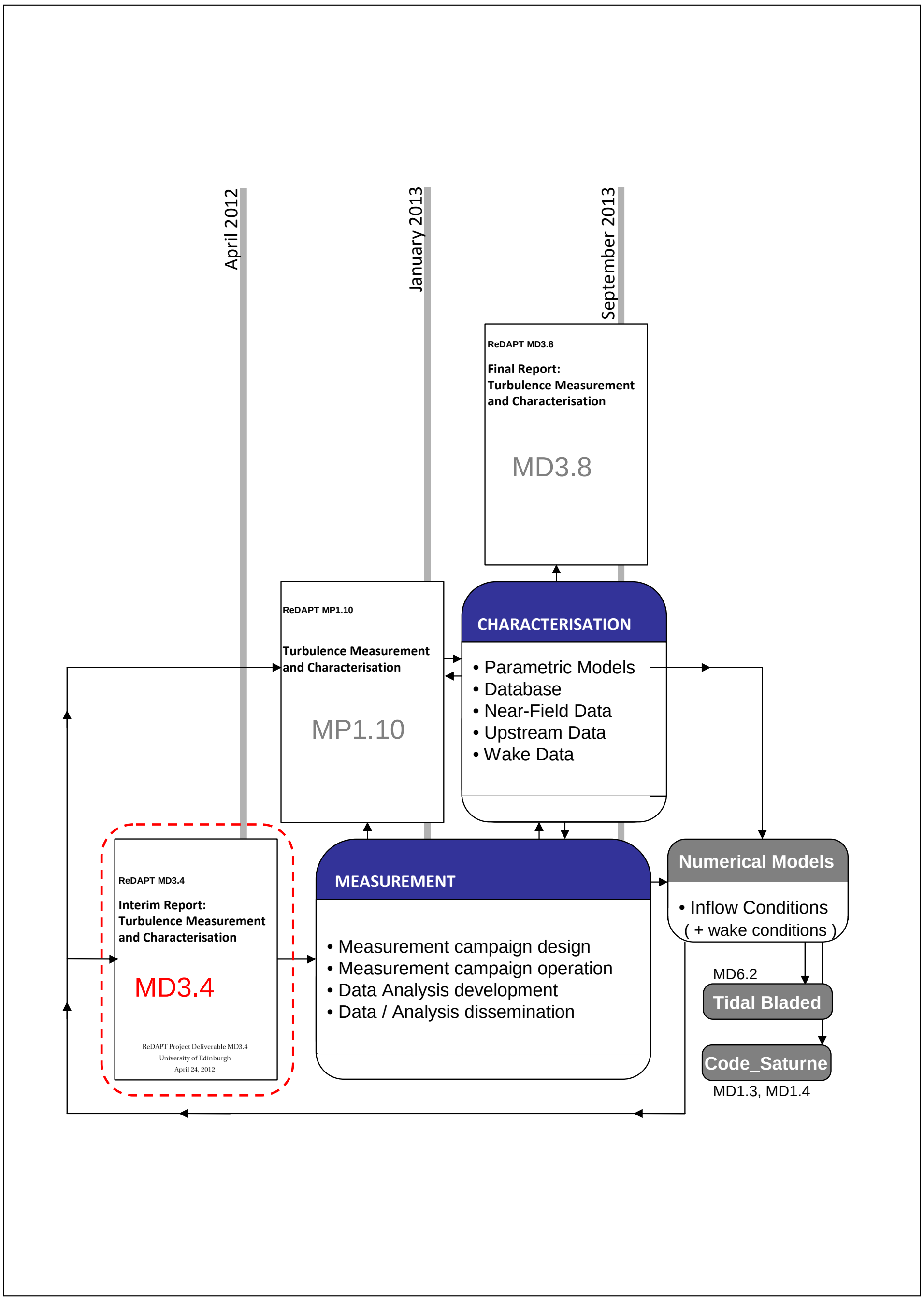


Figure 2: MD3 Reporting Roadmap

3 Statistical Characterisation

The objective of MD3.4 is to characterise turbulent flow where the measurable parameters are by definition random variables. As random variables are inherently unpredictable focusing on probabilistic characterisation is appropriate. [5].

Statistical tools for measuring probability include:

– Probability density functions including joint probability techiques

– The characteristic function

– Probability distributions

– Correlations

– Variances

– Spectra

[5], [6].

The range of complexity of models or descriptions that can be built upon these tools is large and confidence in their use is generally reliant on large quantity of high quality experimental measurements.

3.1 Statistical Analysis: Role in Machine Design and Operation

A central objective of capturing parametric descriptions is to inform machine design so that the performance, longevity and cost effectiveness of future energy extraction devices is improved. Spectra in particular are already widely used in the design of devices in other Renewable sectors, such as Wave and Wind. It is recognised that investigation into the suitability of existing parametric descriptions for use in the tidal sector is required.

Energy Density Spectra, a form of statistical description and an examination of a signal via the energy distribution across signal frequency or wavenumber, are one particularly useful tool in the characterisation of systems [6]. They allow the time domain properties in a statistically stationary process to be represented in the frequency domain, which is significant for processes which display frequency dependency. Also:

- They are relatively straightforward to obtain
- They provide information that cannot be obtained by analysis of the signal in the time domain.
- They can be calibrated and improved upon in parallel to data measurements.
- They can be reversed to provide statistically representative time series of parameters.

Once identified, spectra provide insight into features of the underlying system, such as the likelihood of the occurance of extreme events. This proves highly useful in wave-field studies where, for example, 100 year waves which play a role in the design of marine structures can be described from the anlaysis of the shape of the tail of the utilised spectra.

Cross-correlation functions, which provide a measure of the similarity of two time series, can be used to quantify spatial and temporal relationships within a flow field.

Probability spectra, in contrast, more commonly referred to as density functions, quantify the probablity of instantaneous measurements falling within defined ranges, without consideration of temporal effects. More sophisticated concepts such as joint probability descriptions can also be employed.

The suitability of the aforementioned tools will be investigated as part of MD3 along with others such as cross-spectral density functions, describing the relationship between two time series in the frequency domain and various methods based on wavelet analysis which can be used to model the dependence between two non-stationary time series [7] [8]. Examples and related literature from other fields will be used. Several examples are given in the following sections.

3.1.1 Wave Energy Converters - Resource Characterisation and Loadings

Wave resource can be characterised through spectral descriptions of a particular site. Again, different spectra are used dependent on several factors. Figure 3, showing the Bretshneider spectrum for fully developed wind waves, highlights some of the information that can be obtained from such spectral shapes. [9]. Other examples of spectra include JONSWAP and Pierson-Moskowitz. These spectra provide the distribution of energy across wave frequencies as shown in figure 3.

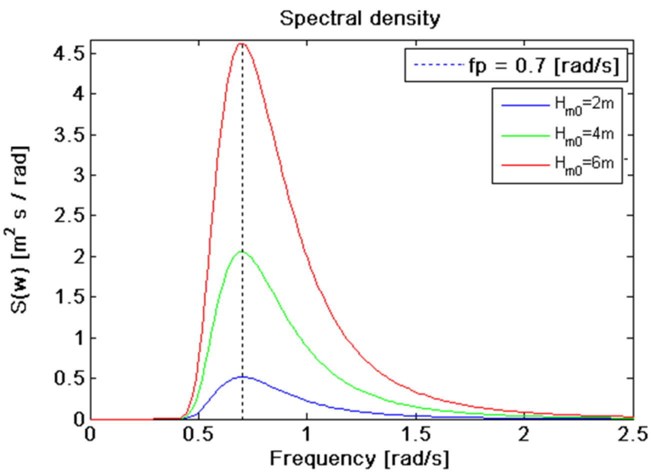
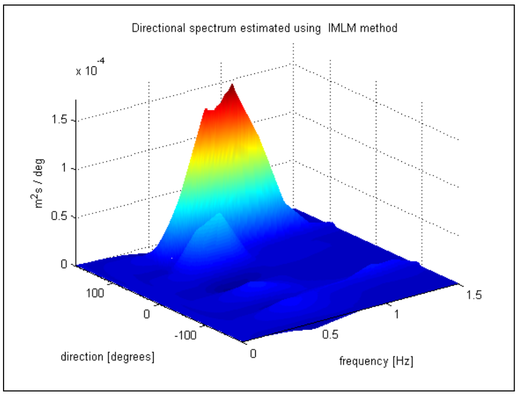
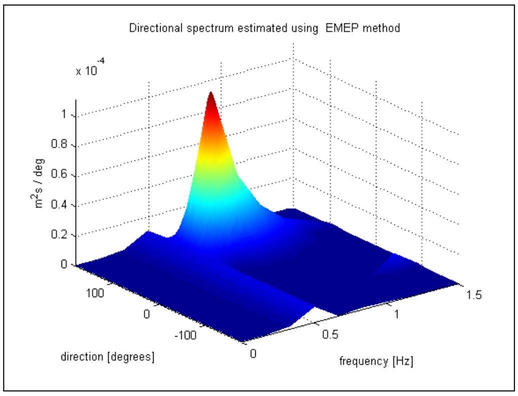


Figure 3: Energy Density Spectrum used in ocean wave modelling - Bretschneider Spectrum

These spectra can be extended to include information on the distribution of energy with direction as shown in figure 4 [10], [11]. This modularity of spectra is another useful feature where complexity can be built up with experience and as improved measurements become available.



(a) Iterated Maximum Likelihood Method



(b) Extended Maximum Entropy Method

Figure 4: Two directional wave spectra generated from the same UoE laboratory data with different estimation methods.

3.1.2 Wind Turbines - Rated Power

Wind and tidal machine cut-in and cut-out speeds are critical design decisions which must be informed by accurate statistics on the environment at the device's location. The probability density function (PDF) of velocities for a given site are employed, which has been found to follow a Weibull distribution for wind. The suitability of a Weibull distribution has not been verified for tidal sites [12].

3.1.3 Wind and Tidal Blades - Effects of Unsteady lift

The lift and drag forces on a lifting surface are a function of speed and angle of attack and, to a lesser extent, Reynolds number and turbulence characteristics. In turbulent flow both the velocity of the fluid and the relative angle of attack are constantly changing, reducing the power that is extracted from the flow, increasing fatigue loads and in extreme cases can cause dynamic stall resulting in large drag forces. The effects can be amplified when the lifting surface is constantly rotating through a stratified environment [13]. The size of the eddies (lengthscales) of the flow will effect the magnitude and frequency of the resulting unsteady forces.

Unsteady lift causes cyclic loading on a turbine blades and thus the ability to predict loads accurately for a given site is vital. Power spectra and coherence functions of velocity times series varying across the rotor diameter and varying over time are required to simulate these hydrodynamic loads [14]. The ability of candidate spectra from the Wind sector (e.g., Von Karman) to be used in the estimation of loading and blade fatigue will be investigated.

For example, extreme and fatigue loads on tidal turbines can be estimated from the numerical modelling of forces produced by two different candidate velocity spectra and integral length scales [14]. Again, further work is needed in developing appropriate spectra for turbulence at tidal sites.

3.1.4 Wind / Tidal Array Control

Control of tidal turbine arrays may depend on the wider spatial variation of flow characteristics over a site. As an example, in the Wind sector, spectral and probability models can inform estimates of wind speeds, which in turn can be used in the design and operation of controllers for large off shore wind turbine arrays. [15]. There are parallels to wake survey and flow and performance modelling and measurement of tidal farms.

3.1.5 Coastal Engineering - Response to Extreme Events

Complex processes in coastal engineering, such as violent overtopping of structures can be modelled using statistical techniques [16]. Of particular relevance to MD3 efforts to characterise response to turbulent flow fields, figure 5 shows a method of assessing the performance of a proposed parametric model i.e., line fitting to the linearised distribution (in this case Weibul). Similar methods could be included in MD3.

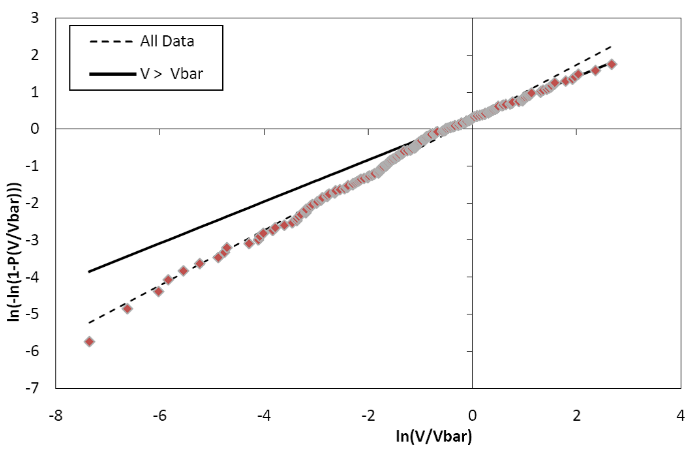


Figure 5: Distribution (Weibull) fitting in coastal engineering sector.

3.2 Statistical Characterisation in MD3

During ReDAPT UoE will collect an unprecedented amount of data on the flow field around a tidal turbine. In order that this data can be used by all workpackages in ReDAPT, efforts will focus on providing appropriate meta data and data access. Project partners' have specified their preliminary data requirements (partly through the development of this document) and at an early stage no parametric modelling is required. Instead the emphasis is on data availabilty and data quality - which involves the development of suitable Quality Control practices. Early data-delivery will focus on traditional statistical flow parameters:

1. Mean flow velocities incident to the turbine (See figure 6)

2. Depth profiles of the mean velocity incident to the turbine

3. Turbulent intensity measured near seabed and near hub-height

Initially, specific attention will be given to turbulence characteristics, particularly intensities and length scales at, or close to, hub height. As confidence in data measurement and analysis improves, more complex parameters and analysis will be included, such as turbulence parameters in the presence of significant wave-fields and in regions surrounding hub-height.

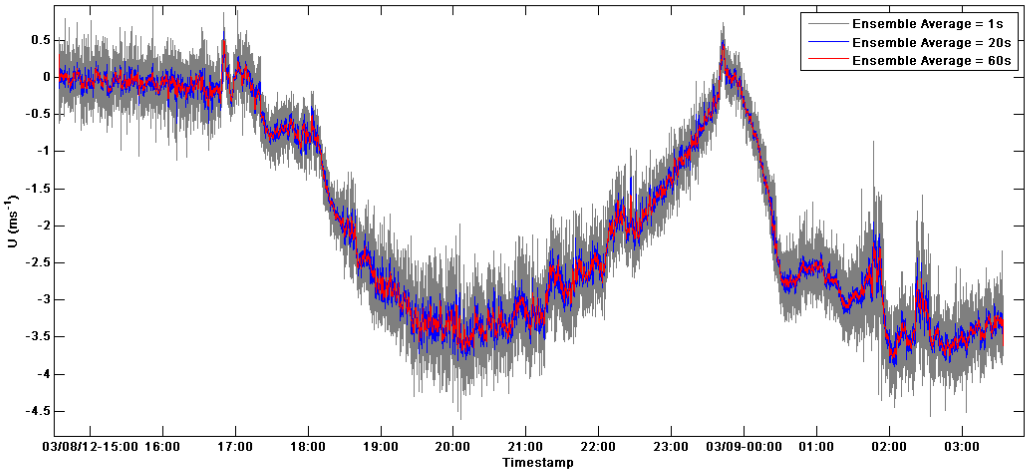


Figure 6: Axial flow velocity, U, 10m above TGL 500KW turbine. March 2012.

3.2.1 Data Processing Considerations

It should, however, be noted that data Quality Control not only plays a role in the provision of relatively simple statistical data sets but has consequences on the future ability to apply and validate spectral models to the data. The following will be considered when selecting and comparing spectral methods:

- There is an element of arbitrariness to PSDs

- Sensitivity of spectra to measurement noise

- Sensitivity of spectra to the method of processing. The estimation method for producing the spectral shape can be important. (e.g., in wave spectral modelling a variety of methods can be used to characterise field measurements and strongly influence results - see figure 4 which is included as an example of this.)

- When taking time series into the frequency domain the level and method of filtering, the level of padding, windowing and data overlap all have effects on the resultant spectral shape and hence any statistical parameters inferred from the spectra.

Looking forward, in order that the MD3 data set can be used to generate simplified, more representative or more generic descriptions of the test site the data must be of both suitable quality and form. The methodology of selecting which measurements to make, to give the best opportunity for susbsequent statistical analysis, has been, to-date, based on:

1. Assessing available instrumentation (currently available / upgradable during the project timescale)
2. Opportunities within the project e.g ., using the tidal turbine itself as a data acquisition platform and making use of parallel measurement activity in the environmental monitoring sub project.
3. Configuring/operating instruments to obtain sufficient data to test some of the underlying assumptions of many spectral models (e.g., turbulent isotropy, homogeneity, stationarity).
4. Assessing which parameters are likely to play key roles in machine design and performance and targetting their acquisition both for study within ReDAPT and for any subsequent analysis.

3.2.2 Tidal Flow-Specific Considerations

Although much work has been done on the theory and measurement of turbulence, particularly in the area of atmospheric flows, there has been little focus specific to turbulence in tidal flows. Tidal channels have several main differences compared with atmospheric turbulence:

- Increased number of boundary layers. Much of the flow field of interest may be exposed to boundary layer effects e.g., seabed, seasurface, coastline.
- Turbulence and flow statistics may be sensitive to parameters other than the mean flow speed e.g., tide direction and bathymetry.
- Characterisation of the flow-field will require the consideration of the effects of a local wave-field.
- Securing good data on which to build models is more challenging.

To develop statistical descriptions and models of turbulence at this ReDAPT test site and in future to other potential development sites we require access to high quality data of the correct form and recorded for sufficient durations.

3.3 Developing Understanding of Available Tools and Preliminary Candidate Models

In parallel to the design and execution of suitable measurement campaigns, early data analysis activity has involved literature review and the collation and standardisation (in terms of nomenclature and variables used) of established techniques and tools. These tools have then been implemented in MATLAB as functions to allow familiarisation and to test the interfaces with the data set. Some of these techniques (collated in table 2 and shown in figure 7) are briefly listed below:

Power spectral density will be produced from velocity time series via the Auto-correlation function. The **Auto-correlation function** is a measure of self similarity of a signal and takes the following form:

$$R_{xx} = \frac{\sum_{1}^{n-\Delta x} u(x,t)u(x+\Delta x,t)}{\sum_{1}^{n-\Delta x} u(x,t)^2} \tag{1}$$

Integral Length scale. The area under the Auto-correlation function gives the Integral length scale of the flow.

$$uL_{xx} = \int_0^\infty R_{xx} d\tau \tag{2}$$

[5]

Where two independent timeseries (e.g., two closely located acoustic instruments) are to be compared the use of **Cross-correlations** will be investigated.

The **Taylor Spectrum** is formed from two point measurements of velocity over a separation distance x as shown in equation 3 and was important in establishing the correlation function as a turbulence metric which defines the slope of the spectra.

$$F(n) = \frac{4}{U}\int_0^\infty R_x cos\left(\frac{2\pi nx}{U}\right) dx \tag{3}$$

[17]

The **Kolmolgorovian**"-5/3" curve is formed from dimensionless analysis based on assumptions that hold for the inertial subrange of turbulent motion. It allows the identification of the inertial subrange of motion of experimental data.

Figure 7 and Table 2 shows well known spectra based upon these inertial subrange assumptions.

Data quality and **Quality Control** post-processing effect spectral shape. This is then generally compared on a logarithmic plot and curve fitting techniques can be used to ascertain the best fit to the classic spectra. Subsequently, spectral parameters can be modified to improve agreement with data. Figures 8a and 8b show examples of experimental power spectral data and corresponding curve fitting. Quality Control, investigated in MD3 to date, involves:

- Signal to Noise Ratio (SNR) based thresholding
- Instrument range based thresholding

Spectrum	Equation	Other info	Ref
Von Kármán	$\frac{fS_u(f)}{\sigma_u^2} = \frac{4 \cdot f \cdot {}^uL_{xx}/\bar{U}}{\left(1+70.8\left(f \cdot {}^uL_{xx}/\bar{U}\right)^2\right)^{5/6}}$		[Morfiadakis, Glinou & Koulouvari 1996]
The Kaimal Spectrum	$\frac{fS_u(f)}{\sigma_u^2} = \frac{4 \cdot L_k/\bar{U}}{f \cdot \left(1+6\left(f \cdot L_k/\bar{U}\right)\right)^{5/6}}$	$L_k = 8.1\lambda$ λ = 0.7z for z<30m λ = 21m for z>30m	[DNV and Risø 2002]
The Harris Spectrum	$\frac{fS_u(f)}{\sigma_u^2} = \frac{3.66 \cdot {}^uL_{xx}/\bar{U}}{f \cdot \left(1+\frac{3}{2}\left(\frac{2\pi \cdot f \cdot {}^uL_{xx}}{\bar{U}}\right)^{5/6}\right)}$	L = 1.09 ${}^uL_{xx}$	[DNV and Risø 2002]
Højstrup	$\frac{f\,S_u(f)}{u_*^2} = \frac{0.5\,fz/u}{1+2.2\,\left(fz/u\right)^{5/3}}\left(\frac{z_i}{-L}\right)^{2/3} + \frac{105\,fz/u}{\left(1+33\,fz/u\right)^{5/3}}$	$u = \frac{k_a V}{\ln\left(\frac{z}{z_0}\right) - \varphi\left(\frac{z}{L}\right)}$ Zi - thickness of the mixing layer	[Panofsky and Dutton 1984]
Davenport	$\frac{nS(n)}{u_f^{\,2}} = 4\frac{x^2}{\left(1+x^2\right)^{4/3}}$	$x = \left(\frac{1200}{z}\right)\left(\frac{nz}{u(10m)}\right) = \left(\frac{1200}{z}\right)f$ $u_f = \frac{C_k U(z)}{\ln(z/z_0)}$ V – Von Karman Constant	[Hiriart, Ochoa and Garcia 2001]
Dryden	$\frac{fS(k)}{\sigma^2} = \frac{2\,{}^ul_{xx}}{f\pi}\frac{1}{1+{}^ul_{xx}^{\,2}k^2}$	K = 2πf /U U – reference velocity	[Wang and Frost 1980]

Table 2: Example spectra. Collated for commissioning of preliminary UoE processing routines.

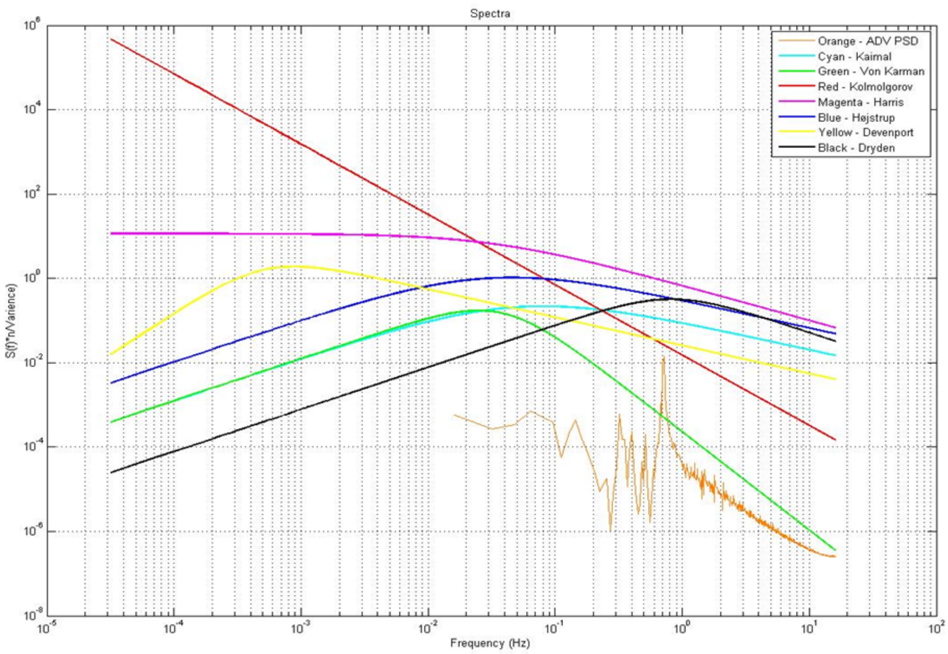
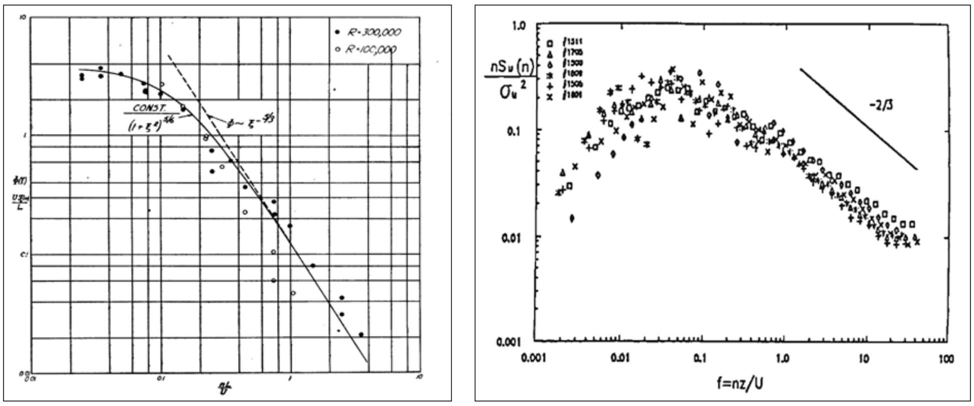


Figure 7: Various candidate spectra trialled in analysis routines. Existing flume-test ADV data (UoE) included as an example.

- Array based considerations (cross-talk, range, SNR, ensemble averaging)
- Standard deviation and Acceleration Thresholding method
- Phase space and wavelet tresholding [18]
- Sensitivity studies on reported metrics after QC



(a) Von Karman, 1948. [19] (b) Wang, 1992. [20]

Figure 8: Experimental validation of spectra

4 Measurement Requirements

A central goal of the "Near-Field" MD3 programme is to supply flow measurement data for the Computation Fluid Dynamic (CFD) modelling programme of MD1. The following categories have been identified during correspondence between ReDAPT partners on data requirements for MD1. Tables detailing the nomenclature and terminology that has been used in group discussions to date are included. These are required (and should be reviewed and updated by the group) to aid clarity and collaboration.

4.1 MD1 Objective - Summary

MD1 has the following objective:

> Develop a 3D CFD model of TGL turbine at EMEC site,allowing the detailed study of the transient flow across the rotor, including the effects of turbulence and waves.

4.2 MD1 Objective - Breakdown

The objective of MD1 is to assess the accuracy with which unsteady loads can be predicted using CFD simulations. The planned comparisons include:

(a) Average thrust coefficient (or mean blade loading) for a range of tip speed ratios.

(b) Average power coefficient for a range of tip speed ratios

(c) Time-varying loads due to simulated flow that has comparable characteristics to the measured flow.

(d) Evaluation of (near) wake turbulence for a representative thrust coefficient and tip speed ratio.

This requires construction of a CFD model with:

- Geometry of the ReDAPT turbine, nacelle and support structure
- Simplified form of the torque-speed control system
- Representation of the ambient flow incident on the ReDAPT turbine.

It is particularly important that the characteristics of the ambient flow incident to the CFD rotor are comparable to the flow conditions at EMEC.

A set of key parameters (not exhaustive) that are required to describe the incident velocity field at the turbine location for a range of mean flow speeds is shown in table 1.

It is acknowledged that the field measurements will not provide a complete description of the incident flow. However, the objective of MD3 is to obtain the turbulence parameters that are expected to influence turbine loading.

A minimum parameter set is shown in table 3.

The foregoing is for AMBIENT flow without rotor (or with rotor off). Some measurements may require yaw of turbine to 90o to flow.

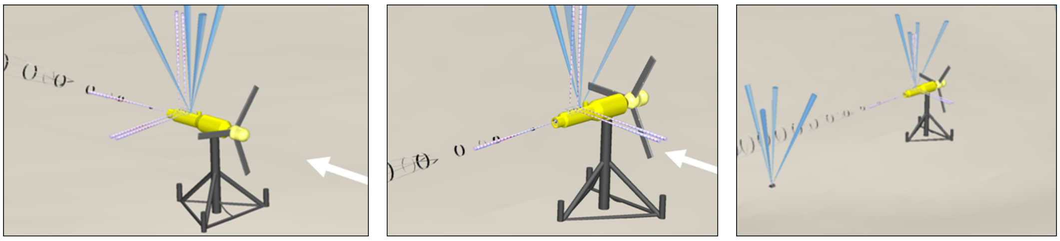
WAKE measurements should focus on the shear layer:

- Lateral or vertical or radial variation of radial velocity and turbulence characteristics
- e.g. Ur(t) at R = 2 m to 16 m gives Ur(R) and TIr(R)

WAKE measurements along axial centreline also of some interest: Ux(t) at multiple X-ordinates downstream.

	Parameter	Location(s)	Data Required
		Profile (z) or Point (zhub)	*Obtain from...*
1	Upstream axial velocity: & turbulence intensity: Longitudinal length scale:	U(x,zhub) Ix(x, zhub) Lx(zhub)	Multipoint correlated U(t,x)(z) Synchronised measurements of U(t) at multiple x-ordinates at hub height.
2	Depth profile of velocity:	U(z) profile V(zhub), W(zhub)	e.g. U(t) at each z-ordinate
	& of Turbulence intensity:	Ix(z) profile Iy(zhub), Iz(zhub)	e.g. U(t) at each z-ordinate (to obtain anisotropy)
3	Lateral length scale:	Ly(zhub)	V(t,y)(z) Synchronised measurements of V(t) at multiple y-ordinates at hub height.
4	Vertical length scale:	Lz(zhub)	W(t,z)(z) Synchronised measurements of W(t) at multiple z-ordinates either side of hub height

Table 3: Limited velocity field parameters



(a) (b) (c)

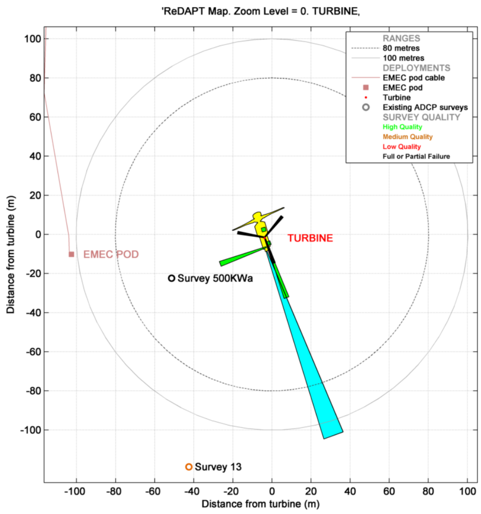
Figure 9: Instrument configurations on the TGL 500KW turbine (TRN01)

5 Meeting the Measurement Requirements

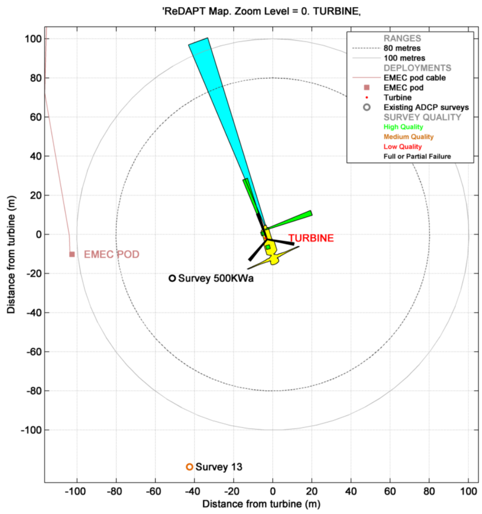
Data will be provided through the deployment of instrumentation on and around the 500KW and 1MW TGL turbines from online and stand-alone configurations. Throughout the programme parameter variability will be investigated to ascertain the minimum level of measurements of a particular parameter that will be required on an ongoing basis. For example, the hard-wired EMEC Pod will contain an ADCP 80-100m west of the turbine. This data will be compared to nearby instrumentation which may result in fewer marine operations being required (if it can be shown that the ADCP provides sufficient information to the group). Identifying minimum levels of data required is a goal of MD3.

5.1 Measurement Acquisition Achievability

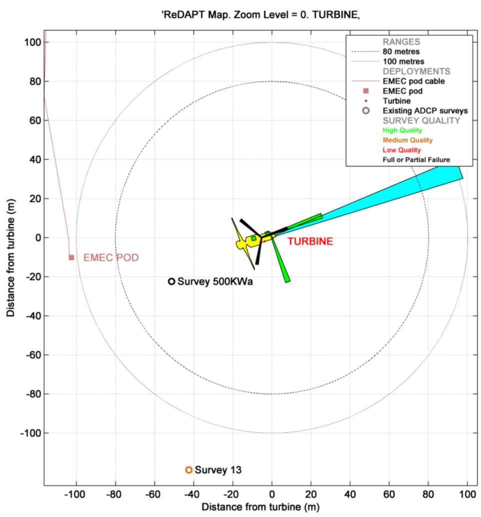
Tables 5 and 6 have been produced through discussions within the group on the data requirements of MD1 and MD5. They are based upon the instrument specification sheet of deliverable MP1.2, subsequently procured data from TGL, MD2.10 and MD2.11 and data requests made by the group (see table 10).Dates are given based on the revised project plan of Contract Amendment 2. Where it is foreseen that the data requested can be met with a high chance of success or where the data exists the “availability” is coloured green. Where there remains some uncertainty of data capture by the given date these requests are coloured amber. Where it is either not possible to provide the requested data by the given date or where research is required on instrumentation and/or analysis these requests are coloured red.



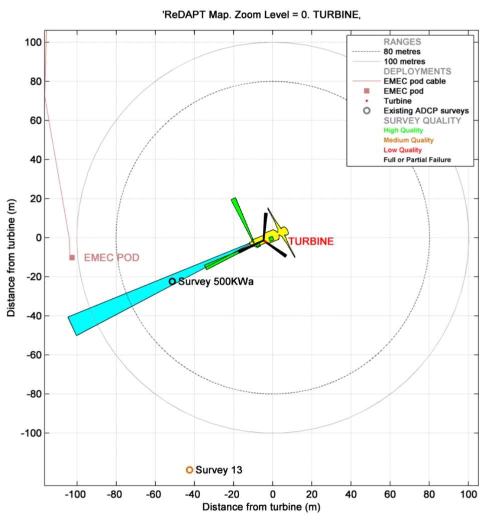
(a) TRN configuration reference 1



(b) TRN configuration reference 2



(c) TRN configuration reference 3



(d) TRN configuration reference 4

Figure 10: TRN test configurations 1 to 4

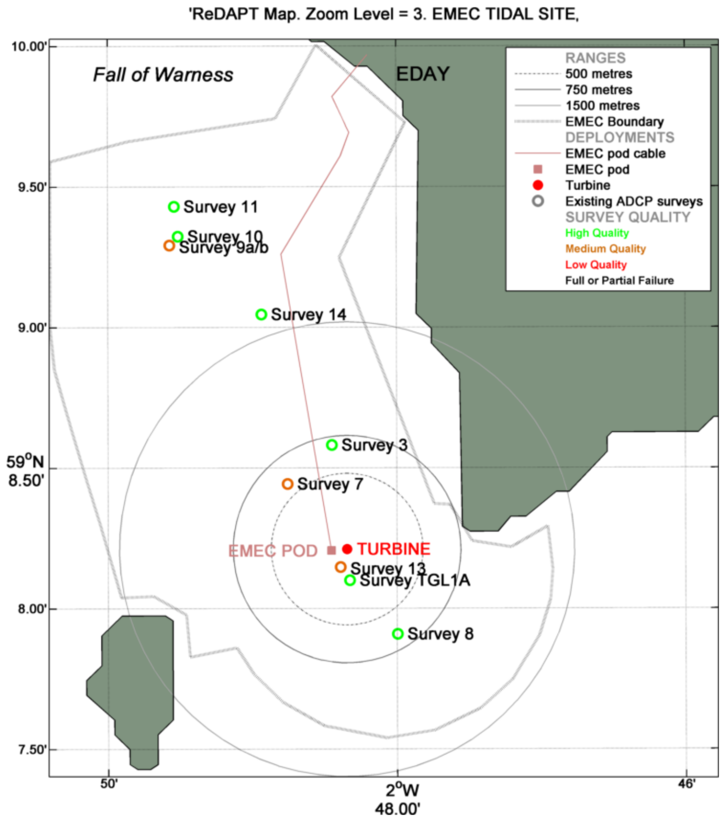


Figure 11: Map of Fall of Warness

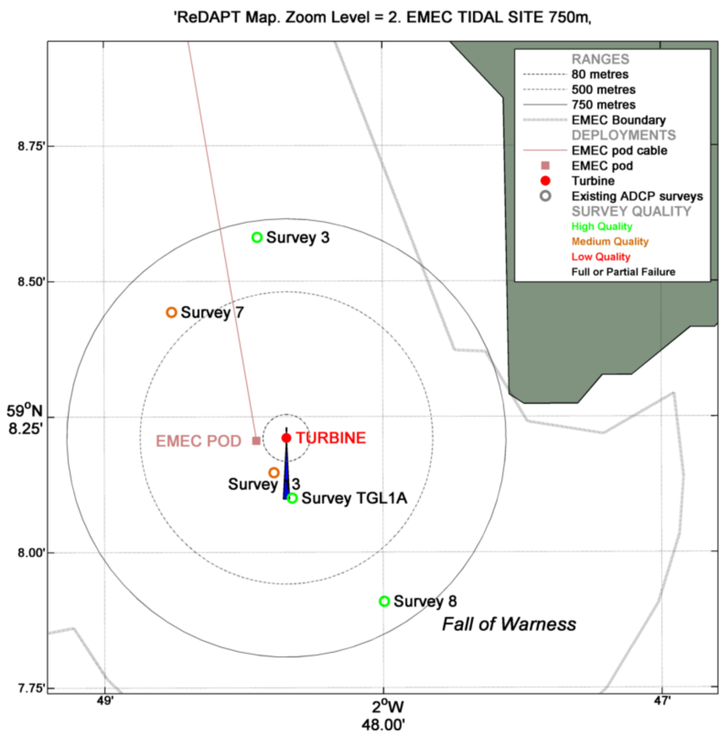


Figure 12: Map of Fall of Warness

5.2 Measurement Schedule

Table 4 shows the MD3 preliminary schedule.

Date Planned	Activity	Work Package
July 2011 (completed)	ADCP dep.	MD2
Aug 2011 (completed)	ADCP data made available	MD2 / MD3
Q1-2012	ADCP dep. 500KW instrument dep. EMEC POD dep. + WAMOS	MD3 MD3 ME1.2 / ME1.3 (tbc)
Q2-2012	ADCP dep. 500KW instrument dep. EMEC POD + WAMOS	MD3 ME1.3
Q3-2012	ADCP dep. 1MW instrument dep. EMEC POD + WAMOS	MD3 ME1.3
Q4-2012	ADCP dep. 1MW instrument dep. EMEC POD + WAMOS	MD3 ME1.3
Q1-2013	ADCP dep. 1MW instrument dep. EMEC POD + WAMOS	MD3 ME1.4
Q2-2013	ADCP dep. Stand-Alone Array dep. 1MW instrument dep. EMEC POD + WAMOS	MD3 ME1.4
Q3-2012	Stand-Alone Array dep. EMEC POD	MD3 ME1.4

Table 4: Schedule outline

(orange) Marine Ops. conducted in winter months

Tech. Difficulty	Priority*	ID	Measurement Direction/Plane	Parameter	Vertical Location (z)	Instrument Type	Instrument Single/Mult	Resolution (m)	Range (m)	Sample Rate (Hz)
	1	1	+x	Luu	hh	AQDII	s	0.4	25	2
	1	2	-x	Luu	hh	AQDII	s	0.4	25	2
	1	3	+z	Lww	hh to η	AQDII	s	0.4	15	2
	1	4	+y	Lvv	hh	AQDII	s	0.4	25	2
	1	5	-y	Lvv	hh	AQDII	s	0.4	25	2
	1	6	+y,+x plane	Luu	hh	AQDII	m	3	3	2
	1	7	+y,-x plane	Luu	hh	AQDII	m	3	3	2
	1	8	+x,-y plane	Lvv	hh	AQDII	m	3	3	2
	1	9	+x,+z plane	Lww	hh to η	AQDII	m	3	3	2
	1	10	+y,+z plane	Lww	hh to η	AQDII	m	3	3	2
Req. Bottom AQDII	1	11	-z,+x plane	Luu	hh to hh-3	AQDII	m	3	3	2
Req. Bottom AQDII	1	12	-z,-y plane	Lvv	hh to hh-3	AQDII	m	3	3	2
Req. P&T	1	13	-z,+x plane	Luu	hh to hh-1	AQDII	m	1	1	2
Req. P&T	1	14	-z,-y plane	Lvv	hh to hh-1	AQDII	m	1	1	2
Req. P&T	2	15	+z	Luu,Lvv,Lww	hh to hh+ 10m	AQDII FB	m	1	10	2
Req. P&T	2	16	+x	Luu,Lvv,Lww	hh+ 5m	AQDII FB	m	1	10	2
Req. P&T	2	17	-x	Luu,Lvv,Lww	hh+ 10m	AQDII FB	m	1	10	2
Req. P&T	2	18	+y,-y plane	Luu,Lvv,Lww	hh+ 5m	AQDII FB	m	1	10	2
	2	19	+z	Lww	bed-η	RDI ADCP	s	1	40	2

Table 5: MD3 Target parameters, implementation and prioritisation.

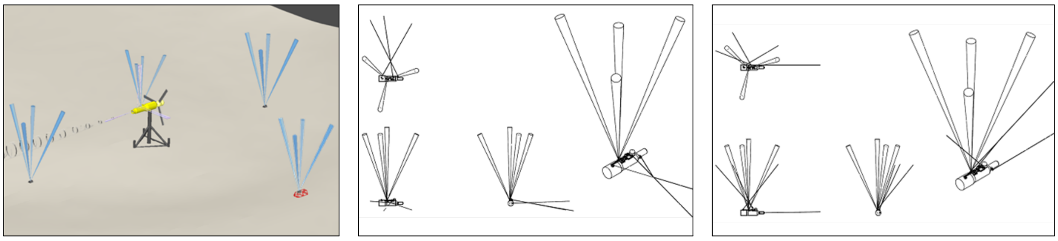
Available or acquisition is low risk
Some issues TBC or configurations to be trialled
Requires significant experimentation.

Tech. Difficulty	Priority*	ID	Measurement Direction/Plane	Parameter	Vertical Location (z)	Instrument Type	Single/Mult	Resolution (m)	Range (m)	Sample Rate (Hz)
	2	20	+z	Lww	hh-?	Nortek AWAC	s	1	20	2
	2	21	+x	Luu	hh	Nortek LRADP	s	5	<200	1
	2	22	-x	Luu	hh	Nortek LRADP	s	5	<200	1
Req. P&T	3	23	>1 of u,v,z	Reynold Stresses	rotor plane	AQDII FB	m	tbc	tbc	tbc
Req. P&T	3	24	u,v,z	TKE	rotor plane	AQDII FB	m	tbc	tbc	tbc
Req. ADV	3	25	High Freq u,v,z	Dissipation Rate, ?	bed+2, hh	ADV	s	tbc	tbc	≈ 16
Req. P&T	3	26	u,v,z in wake	Wake parameterisation	wake	AQDII FB	m	tbc	tbc	2
Req. P&T	3	27	u,v,z nearfield	Fatigue load drivers	nearfield	All	m	tbc	tbc	2
	3	28	sparse grids of pairs	Statistically modelled	bed to bed+25, hh to hh+25	All	m	2	20mx20m	2
			or triplets of u,v,z							
	1	29	point	?	surface	AST,AWAC,P	m	<0.05	to surface	4
	2	30	point	?	surface	ADCP,P	s	<0.1	to surface	4
	2	31	-x	?	surface	ADCP,P,AST,AWAC,P	s	100	200	4
	2	32	+x	?	surface	ADCP,P,AST,AWAC,P	m	100	200	4
	2	33	+x	?	surface	P	m	1	5	2
	1	34	point	Hm,Tp,Dm,?	surface	ID 28-32	m	See MP1.2	See MP1.2	10 mins
	2	35	point	Iz	bed to ?	ADCP	s	See MP1.2	See MP1.2	2
	2	36	point	U,V,W	bed to ?	ADCP	s	See MP1.2	See MP1.2	2
	1	37	+x/+y	Iz	bed to ?	ADCP/AWAC/EMEC POD	m	200	200	2
	1	38	+x	Iz	turbine to ?	ADCP/AWAC	m	100	200	2
	2	39	+x/+y	U,V,W	bed to ?	ADCP/AWAC/EMEC POD	m	200	200	2
	2	40	+x	U,V,W	turbine to ?	ADCP/AWAC	m	100	200	2

Table 6: MD3 Target parameters, implementation and prioritisation (continued).

5.3 The 1MW instrument array

The 1MW has more capability to measure velocities across planes due to increased sensor number and increased horizontal and vertical instrument separation. An increased number of configurations will be made possible due to the inclusion of subsea pan and tilt units.



(a) Multiple ADCP deployments around 1MW turbine (b) Candidate instrument configuration (c) Candidate instrument configuration

Figure 13: Instrument configurations on the TGL 1MW turbine (TRN02)

Survey / Action	Latitude deg minutes N	Longitude deg minutes W	Depth (m)	Number of Days	Ensemble period (s)	Packets	File Size
Survey 3	59°08.581’	002°48.449’	35.7	13.9	1200	yes	18.9MB
Survey 7	59°08.443’	002°48.757’	49.3	33.2	600	no	21.1MB
Survey 8	59°07.909’	002°47.996’	36	14	1200	yes	27.8MB
Survey 9a	59°09.292’	002°49.572’	30.5	8	1200	yes	2.8MB
Survey 9b	59°09.292’	002°49.572’	30.5	20.9	1200	yes	32.7MB
Survey 10	59°09.323’	002°49.515’	26.4	40.7	1200	yes	66.7MB
Survey 11	59°09.430 ’	002°49.540’	15.1	25	1200	yes	35.5MB
Survey 13	59°08.147’	002°48.391’	36.2	32	30	yes	305MB
Survey 14	59°09.046’	002°48.935’	35.2	31.4	0.5	no	1.17GB

Table 7: EMEC DHI data set

As part of MD2 (MD2.10) EMEC have made available the data set summarised in table 7. This comprises nine ADCP surveys conducted over several years which have been delivered, as part of ReDAPT, to a sub-contractor for use on the tidal site modelling work of MD5.

As can be seen from the map in figures 5 and 5, Surveys 3, 7, and 8 are within 750m of the turbine with Survey 13 and Survey TGL1A within 200m of the turbine.

This data set is now available online.

TGL Near (200m) Turbine Data Set

As an exceptional case an existing ADCP data set, recorded from within 200m of the turbine location, was provided by TGL for use on the ReDAPT project.

This data set is now available online.

Survey / Action	Latitude deg minutes N	Longitude deg minutes W	Depth (m)	Number of Days	Ensemble period (s)	Packets	File Size
Survey TGL1A	59°08.188’	002°48.326’	35.7	30	Raw @ fs=2Hz	no	1.2GB

Table 8: TGL data set

6 Acquiring New Measurements

This section covers data acquired under the ReDAPT programme from 2011 including recently secured MD2 data sets and future MD3 data sets from both the 500KW and 1MW turbine and the surrounding seabed. Additionally, ME data may be acquired from Shore and the seabed located EMEC Pod.

- Seabed
  - Site-Wide = MD2 ADCP deployments.
  - <100m of turbine = EMEC POD
  - <200m of turbine = ADCPs forward and rearward of turbine.
  - <200m of turbine = Instruments installed on stand-alone seabed frame.
- Shore
  - EMEC WaMoS system (as part of ME)
  - EDAY met. station (as part of ME)
- Turbine Platform
  - Instruments installed on 500KW turbine
  - Instruments installed on 1MW turbine

6.1 Measurements from the Seabed

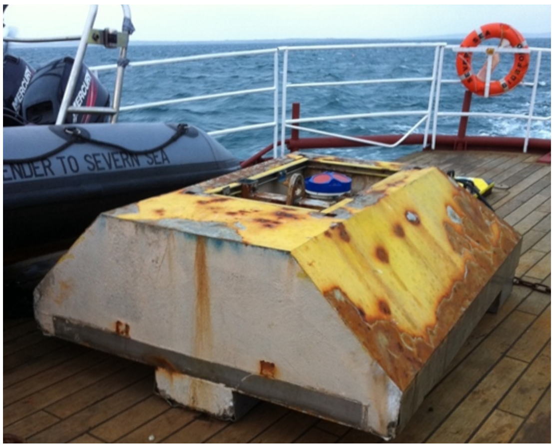
Survey / Action	Latitude deg minutes N	Longitude deg minutes W	Depth (m)	Number of Days	Ensemble period (s)	Packets	File Size
Survey D1	59°07.72’	002°48.79’	40m tbc	30	Raw @ fs=2Hz	no	2Gb
Survey D1-2	59°07.72’ tbc	002°48.79’ tbc	40m tbc	30	Raw @ fs=2Hz	no	2Gb
Survey S1	59°04.004	002°44.160	40m tbc	30	Raw @ fs=2Hz	no	2Gb

Table 9: UoE ReDAPT MD2 ADCP data sets

This data set is now available online.

ADCPs forward and rearward of turbine

ADCPs will be deployed forward and rearward of the TGL turbine in configuration as shown in figure 13a. Efforts will be made to deploy the units within 100m of the turbine. These deployments will address far inflow and wake current velocities, turbulent intensities and site wide wave statistics.



(a) Pre-deployment. UoE ADCP in TGL seabed frame. Image c/o Liam Warren TGL Ltd.

(b) Deployed. ADCP in TGL seabed frame. Image c/o Liam Warren TGL Ltd.

Figure 14: RDI ADCP on the Severn Sea (a) and on the seabed (b)

Stand alone deployed Aquadopp II

DESIGN TO FOLLOW Q3 2012.

Following use and development of the AQDII array on the roof and tail of the 500KW and 1MW turbines the units will be removed, integrated into a custom seabed mounting frame and deployed to investigate far (<200m) inflow and wake current velocities (and wave statistics) in more detail with an emphasis on turbulence measurements. These deployments are scheduled to commence in Q3 2012.

EMEC Pod

The EMEC pod is scheduled to be deployed in Q1 2012. Whilst the outputs of the pod are not directly tied in to the MD sub-project the data it produces will be useful. We are particularly interested in access to:

– ADCP data

– Salinity data

– Temperature data

– Conductivity data

ADCP data can be used by MD3 for baseline mean flow speed near the turbine (<100m). Salinity and temperature data can be used by MD3 in sound speed correction processes. Ongoing discussions on the ReDAPT data management system aim to address issues related to resource allocation and access mechanisms to enable this data to be shared within the group.

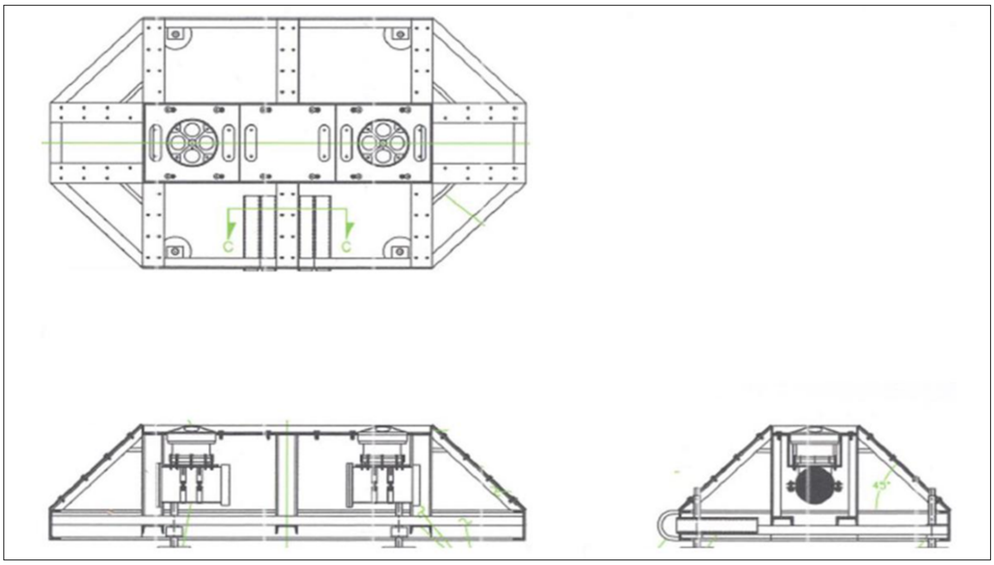


Figure 15: CAD model - EMEC POD concept

6.2 Measurements from Shore

- Time-Stamping will be achieved by a master clock installed in the EDAY substation.
- EMEC WAMOS - Provide site wide wave and surface current statistics.
- EMEC Met data

Data management strategy discussions are ongoing and some data access is currently subject to Variation Requests.

6.3 Turbine Platform Measurements

6.3.1 Measurements on the 500KW TGL Turbine

The 500KW machine (500KW) will be deployed throughout autumn and winter 2011. In keeping with original (post VR008) schedules, instrumentation will be made available by UoE for installation on the turbine (500KW swapped in for 1MW due to over-runs on manufacture) in December 2011. Early stage feasibility studies indicate that up to six Aquadopp II instruments can be retro-fitted to the 500KW along with a 1MHz AWAC, pressure transducers, Inertial Measurement Units (IMUs), Instrument

Control Box (ICB) and a long range, 198kHz Continental. Proposed layouts to meet Requirements are shown below. These are concepts only and there will be time needed for instrument commissioning, troubleshooting and optimisation. October 2012 has been allocated for design and interface work scope. Concepts with the least unknowns have been included below to aid discussion.

6.3.2 Measurements on the 1MW TGL turbine

Instrumentation will be installed on the TGL 1MW turbine when the turbine becomes available (expected June 2012). Instrumentation comprises 15 x AQD2 forming a modular, flexible array, 1 x AQD2 on the turbine nose cone, 1 x MHz AWAC on the top, 1 x 198kHz long range Continental on the rear of the turbine.

The TRN process has now commenced and test configurations are being developed with TGL, EDF/UoM and GLGH. The next issue of this report will include test configurations on the 1MW turbine.

7 Notes on Data Access and Data Analysis

7.1 Access to Data

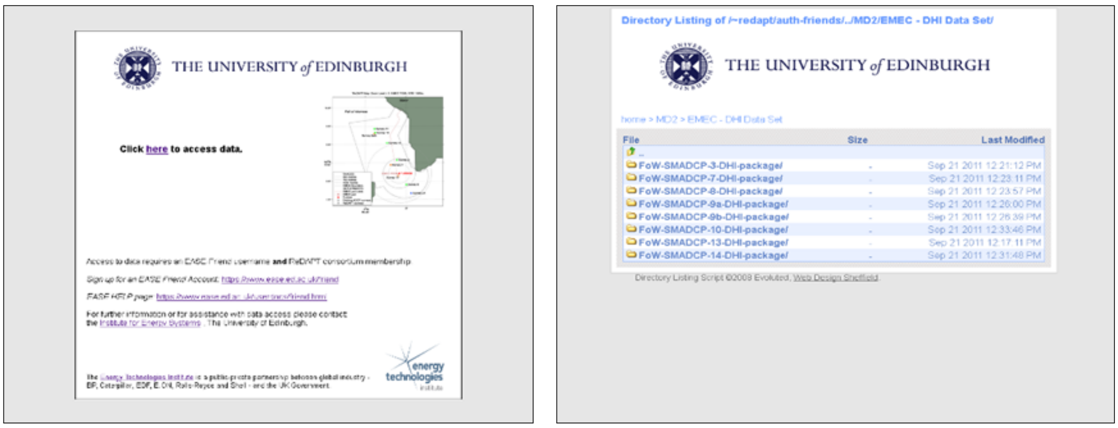
Existing and future data is available for use and further analysis by the group at:

`http://www.see.ed.ac.uk/~redapt`

ReDAPT group members can access the data by a single page sign-up process to the University's external user restricted website access mechanism - EASE Friend:

`https://www.ease.ed.ac.uk/friend/`

NB. Once you have signed up please email *Brian.Sellar@ed.ac.uk* with your sign in email address so that you can be manually authorised to access the data repository.



(a) (b)

Figure 16: Screenshots of the preliminary UoE Database

As of 5th October 2011 the following data sets are available for download online:

- Survey D1 (Model Construction)
- Surveys EMEC-DHI
- Survey TGL1A
- Survey N1 (north FoW tide gauge elevation)

Available from 18th - 28th October 2011:

- Survey D2 (Model Validation)
- Survey S1 (south FoW flow)

Available from week 1 / week 2 May 2012:

- 500KW AWAC dataset
- 500KW Continental dataset
- 500KW Aquadopp II/SBD datasets
- ADCP (65m south west of 500KW) dataset

7.2 Notes on Analysis

All future acquired binary instrument data will be made available to the group in addition to post Quality Control data sets in ASCII format. Time stamping will be referenced to clock of the Nortek Eday GPS master timer and reported in ISO 8601 format: YYYY-MM-DDThh:mm:ss Where manufacturer's proprietary software reports times in a different format these will be re-processed.

Existing binary instrument data will be supplied where available.

7.2.1 Wave Parameter Analysis

There remains uncertainty around processing and analysis of directional spectra. There are three choices for the analysis: use instrument manufacturer supplied software, third-party software or develop custom routines.

RDI ADCP instrument data is processed by WavesMon software with directional spectra generated by the iterative maximum likelihood method (IMLM). Nortek AWAC data can be processed by Nortek's WaveExtract. Literature and open-source tools exist for the interpretation of ADCP data.

Implementing a suitable waves processing methodology will be investigated and discussed within the group. UoE will process the data using instrument manufacturer supplied software and through MATLAB based toolboxes produced by the oceanographic community. In-house MATLAB pre-processing / post-processing routines will be developed and where appropriate compared to existing techniques.

Parameter to be specified	Recommendations
Minimum Wave Period (non-directional)	3 / 4 seconds (dep. on config.)
Minimum Wave Period (directional)	4 / 5 seconds (dep. on config.)
Cut-off Frequency (Low)	0.025Hz-0.05Hz
Cut-off Frequency (High)	<= Nyquist, 0.5 fs
Frequency Resolution	>0.01Hz

7.2.2 Current Parameter Analysis

University of Edinburgh data QC will be based upon manufacturer's guidance, current practice in industry (e.g., EMEC) and guidance from current literature including QARTOD and Equimar. Where appropriate in-house pre-processing and post-processing will be applied in conjunction with instrument manufacturer propriety software.

Notes

- Where available raw data will be made available in binary format and post-QC ASCII data.
- QC and processing activities will be described in accompanying documentation.
- No ensemble averaging will occur at an instrument level (this can be achieved in post-processing where necessary).

7.2.3 Turbulence Parameter Analysis

In order to meet the project goals of MD3, culminating in the final report on turbulent characterisation in September 2013, many elements of instrument operation and data analysis will require investigation. MD3.4 aims to highlight these areas of study and to invite input from the project partners to help meet the wider MD3 and ReDAPT goals.

The following list contains the areas of study that have been identified to date:

- Liaise with MD1.3 and MD1.4 work package group on the current best practice for inputting turbulence parameters to CFD models.
- Identify, track and characterise the occurrence and progression of flow features across or through data measurement grids / volumes using AQDII array.
- Investigate the ability of AQDII in novel configurations to identify flow velocities in three component directions.
- Investigate the ability of this arrangement to examine multiple 'points' around the turbine (both forward, rearward, above and below).
- Investigate the suitability and relevance of available guidance on parameterisation of wave and current measurements (e.g., Equimar).

- Record data comprehensively over the full range of site conditions and archive in an appropriate manner such as to allow future analysis of the data set to allow testing of new analysis methods, comparisons of more limited studies and as a benchmark data set.
- Parametric modelling techniques (see section 1)
- Investigate the ability of available instrumentation (e.g., ADPs and ADVs) to infer turbulence characteristics and their relevance to the tidal turbine sector:
  - Time Windowing thresholds for stationary statistics of time series data
  - Length scales
  - Turbulent Kinetic Energy
  - Dissipation rate
  - Instantaneous velocities in the presence of Doppler noise
  - Depth profile of parameters (e.g., I, U, TKE)
  - Cross correlations of time series signals.
  - Analysis methods appropriate for sparse data arrays

8 Establishing Operational Procedures for Measurement Acquisition

8.1 Test Request Notices (TRNS) and the UoE Test Management System (TMS)

The ReDAPT partners have various measurement and analysis requirements and goals. There is a need for a clear methodology to request and execute tests which will assist in test prioritisation, scheduling and planning throughout the ReDAPT data measurement programme.

It has already been identified that the project will make use of the established Rolls Royce Test Request Notice (TRN) process. TRNs will assist the programme by allowing efficient and clear information on tests to be conducted and tests that have been carried out. Due to the interdependency of data requirements, instrument configuration and data processing an attempt to aid the integration of TRNs with the instrument test management system has been introduced in MD3.4 in Appendix A. This Test Management System will be used to configure, operate and acquire data from the instruments available to MD3 and to allow interfacing with external data and data systems for example, TRNs, GLGH's SCADA system, and ReDAPT data libraries. It is hoped that through discussion driven by MD3.4 features of the test management system can be developed and refined.

Feature list of the UoE TMS

- Linked to RR TRN unique IDs

– Interfaced with UoE software for controlling hardware (Test Management System)

– Auto-generation of meta-data with appropriate archiving methodology

– Flags scheduling conflicts

– Deployed on MATLAB and UoE MySQL server (see figure 17)

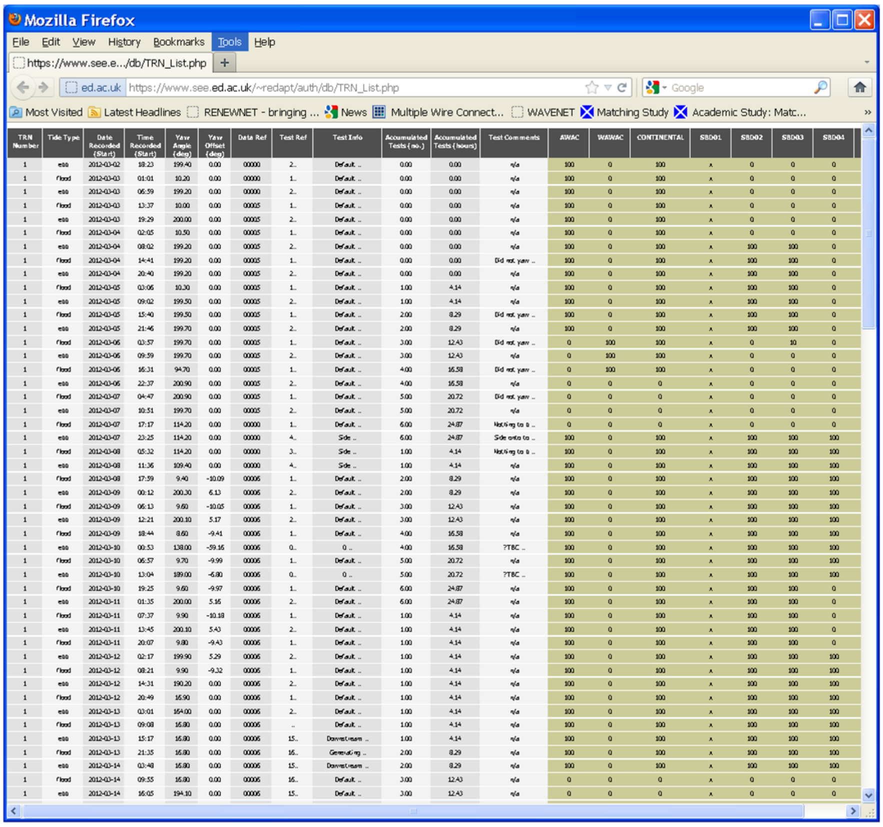


Figure 17: Screenshot of the new UoE MD3 database

Data Requested	Supplied by
Far Wave spectra	High-Q Survey 3 and 8 (750m) High-Q 14 (1500m) THE FOLLOWING TIME SERIES HAVE NOT YET BEEN PROCESSED FOR WAVES STATISTICS: UoE received TGL data-set (TGL1A).(<250m) High-Q D1 (1500m) and High-Q D2 (1500m) FOR LATER COMPARISON: WAMOS for spatial homogeneity of wave statistics.ă
Far Mean flow. Depth Profile	High-Q Survey TGL1A. Low-Q Survey 13 (200m) High-Q Survey 3 and 8 High-Q Survey 14 High-Q Survey D1 High-Q Survey D2
Far Turbulent Intensity, I. Depth Profile	THE FOLLOWING TIME SERIES HAVE NOT YET BEEN PROCESSED FOR TURBULENT INTENSITY: High-Q Survey TGL1A. High-Q Survey 14 High-Q Survey D1
Site-Wide Wave statistics Hm0,Tp, S(f), S(f,?)	WAMOS Seabed mounted ADCP forward and rearward of turbine. PLUS ALREADY AVAILABLE: EMEC-DHI Data Set High-Q Survey 14 High-Q Survey D1 High-Q Survey D2 THE FOLLOWING TIME SERIES HAVE NOT YET BEEN PROCESSED FOR WAVE STATISTICS: High-Q Survey S1 High-Q Survey TGL1A.
Near Wave statistics Hm0,Tp, S(f), S(f,?)	Online AWAC on 500KW and 1MW turbine. Pressure Gauge available for point comparison. THE FOLLOWING TIME SERIES HAVE NOT YET BEEN PROCESSED FOR WAVE STATISTICS: High-Q Survey TGL1A
Near Wave elevations	Online AWAC on 500KW and 1MW turbine. Pressure Gauge available for point comparison.
Far (<200m) Inflow and Wake velocity. Depth Profile	Seabed mounted ADCP forward and rearward of turbine. (involves winter deployments)
Far (<200m) Inflow and Wake velocity. Fluctuations. Turbulent Intensity. Depth Profile	Seabed mounted ADCP forward and rearward of turbine. (involves winter deployments) No seabed AQD II array available until Q3 2012
Near Inflow velocity. St/wise multi-point. Rotor On	No AQD on nose. Trial of through-blade AQD II.
Near Inflow velocity. St/wise multi-point. Rotor Off	Supplied by AQD II array. Yaw turbine 90 degrees.
Near Wake velocity. St/wise multi-point. Rotor On/Off	AQD II array
Far (<200m) Wake velocity. St/wise multi-point. Rotor On/Off	ADP Continental
Far (<100m) Inflow velocity. Fluctuations. Horizontal Plane	No seabed AQD II array available until Q3 2012
Far (<100m) Inflow velocity. Fluctuations. Vertical Plane	No seabed AQD II array available until Q3 2012
Near Inflow velocity. Mean. Horizontal Plane	AQD II array on 500KW. 3 to 4 Beams. Pre-1MW configuration limited by number of AQD II. Focused AQD II cluster will be trialled.
Near Inflow velocity. Fluctuations. Horizontal Plane	AQD II array on 500KW. 3 to 4 Beams. Pre-1MW configuration limited by number of AQD II. Focused AQD II cluster will be trialled.
Near Inflow velocity. Fluctuations. Vertical Plane	AQD II array on 500KW. 3 to 4 Beams. Pre-1MW configuration limited by vertical separation of AQD II. Focused AQD II cluster will be trialled.

Table 10: Provisional data set requests from MD partners (Jan 2012)

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