Appendix 10: Data collection, analysis and provision

FaB Test

Falmouth Bay Test Site
Marine Renewables Commissioning Site

Dr Ian Ashton, Marine Renewables Oceanographer – FaBTest,
Robin Blundy, Computing Development Officer - FaBTest
Violette Harnois, Marine renewables research associate – FaBTest
Alex Whatley, Operations manager - FaBTest
Antoine Morvan, Associate Research Fellow
Prof Lars Johanning, Associate professor in Ocean Energy

Offshore Renewable Energy group, Renewable Energy, College of Engineering, Maths and Physical Sciences, University of Exeter, Penryn Campus, Cornwall

Executive summary

The data collection, analysis and provision work underway by the FaBTest team is designed to incorporate research advances in the measurement and classification of oceanographic conditions, and their interpretation for engineering projects into an automated system providing data and analysis to site users at FaBTest. This report details progression in that work. It describes data collection systems and key procedures that have been setup. The report also covers progress in ongoing research and gives details of how these are being incorporated into the offer of services for those testing at FaBTest. The outcome demonstrates how the FaBTest team are collecting and using data. It also shows how the work underway will bring a wide range of high quality, innovative data products to site users, helping them draw detailed analysis of their test phases, and benefits to local supply chain and stakeholders. This report provides site users and prospective site users with information about the processes ongoing and it is hoped will encourage them when planning their tests as well as helping optimise their test period on site.

The FabTest site is leased from The Crown Estate and has consent for testing, subject to permits issued by Falmouth Harbour Commissioners. Operational support of the site, as well as the ongoing monitoring and world leading research, is provided by the Renewable Energy Group from the University of Exeter, based on the nearby Penryn campus, and is made possible in part thanks to an investment of Regional Growth Fund money. The RGF investment of £549,000 into FaBTest was approved by the Cornwall and Isles of Scilly Local Enterprise Partnership (LEP). The LEP recognised FaBTest as a key investment priority and a unique asset which can create economic benefits and market opportunities. The Regional Growth Fund is managed locally by Cornwall Development Company on behalf of the LEP and Cornwall Council.

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1.1	Draft	Ian Ashton	28/07/2014	Added data flow diagram. Would benefit from some technical content in section 3. Still requires formatting, logos and proof reading
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1.3	Draft	Ian Ashton	18/08/2014	Further changes to section 3. Draft ready for proof reading
1.4	Draft	Ian Ashton	24/09/2014	Alterations to figure numbering, final draft still requires further proof reading
1.5	Draft	Alex Whatley	10/10/2014	Additional information covering deployment process and web links to supporting documentation
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Authorisation		Lars Johanning		

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1 FaBTest overview

FaBTest is an award-winning, pre-consented, 2.8km^2 test area situated within Falmouth harbour, between three and five kilometres offshore in Falmouth Bay. This nursery facility enables device developers to test components, concepts or full scale devices in a moderate wave climate, whist giving excellent accessibility to the device and benefitting from extensive nearby port infrastructure.

FaBTest's pre-consented status, which allows for up to three devices to be deployed concurrently, aims to provide a fast, flexible low risk and low cost solution for the testing of marine energy technologies, components, moorings and deployment procedures. The site offers water depths of 20m-50m and seabed types of rock, gravel and sand.

FaBTest characteristics:

- Within Falmouth Port limits
- 4.5 km from Falmouth Harbour entrance
- 7.5 km from dock area
- In the lee of the Lizard Peninsula (reduced exposure to the prevailing SW wind and swell)
- Exposed to waves from the E - SE
- Peak tide height range ~6.0 m
- Peak tidal surface current ~ 0.8 m/s
- Adjacent to extensive dock facilities incorporating three dry docks, wharf space, cranage and a heavy load out quay
- Access to an experienced supply chain, with an impressive track record in delivering marine renewable energy projects
- Support from world leading research by the University of Exeter

FaBTest is a pre-consented site for the development and testing of Marine Energy Convertors (MECs). FaBTest is a nursery site and not grid connected, so all generated power must be consumed on site via a dump load. The site's pre-consented status reduces risk, uncertainty, time and cost, which is especially appreciated by device developers at pre-commercial investment stage. So long as a device design fits within the defined "Rochdale envelope" of permitted devices, the site operators can offer certainty of deployment permission, subject to scheduling and availability on the three berths. FaBTest also supports supply chain activity in the area and facilitates world-leading, multi and inter-disciplinary research for the marine renewables sector from the University of Exeter.

The pre-consent allows the following types of devices to be deployed, subject to permits issued by Falmouth Harbour Commissioners:

- Substantially buoy-shaped device with a maximum diameter of 30m;
- Substantially box-shaped device with a maximum dimensions of 30m x 30m or equivalent area
- Substantially tubular-shaped device with a maximum length of 180m;
- Floating platform type device with maximum dimensions of 35m x 35m or equivalent area; and Subsystem connectors and umbilicals

Mooring systems are restricted to gravity and drag embedment anchors. Guarded underwater turbines are also permitted and work is underway towards achieving consent for a defined range of floating wind devices in the near future.

Thanks to the pre-consented status, the application process for deployment on FaBTest is relatively straight forward. The application requires evidence of engineering due diligence, environmental and other risk assessments, as well as deployment and decommissioning plans and evidence of required insurance and financial bonds.

Detailed requirements are set out in the detailed deployment documents, which can be found online at http://fabtest.com/deployment. The following documents are available and are designed to aid in the consultation and project development:

1. Guide to deployment
2. FaBTest Operating policy
3. Appendix 1 Procedure Overview Diagram
4. Appendix 2 Provisional-Booking Form
5. Appendix 3 Application Form
6. Appendix 4 Engineering Risk Assessment
7. Appendix 5 Specifications for Navigational Safety
8. Appendix 6 Baseline Studies - Environmental Monitoring
9. Appendix 7 Seabed Habitat Risk Assessment
10. Appendix 8 QHSE Guidance Templates
11. Appendix 9 FaBTest site characteristics

2 Introduction

Data collection at the FaBTest site is designed to provide optimum support to devices and components being tested on site. It is operated by the University of Exeter Offshore Renewable Energy group; an applied research team that comprises experienced researchers and dedicated technical staff, actively engaged in the ongoing characterisation of physical environmental conditions at the site. The data incorporate in-situ measurements and modelling of the physical environment as well as direct measurements of device performance.

The data collected at the site are subject to rigorous quality control procedures. These provide data of the highest quality, suitable to detailed research and development. Data are supplemented by core analysis procedures to classify the oceanographic environment and to support the prediction of loading and fatigue on installed devices. As such, it combines long term data collection for classification of the site conditions and real time measurement and assessments for monitoring and control of ongoing operations.

Incorporating this research and other developments into automated data collection and analysis systems is providing site users with the best possible information for planning, conducting and reviewing their tests. It also has the potential to provide local collaborators and the wider community with benefits for all maritime activities.

This document provides details of work undertaken so far, including data collection, quality control, processing, analysis and the provision of data to site users and other relevant parties. The document also describes ongoing procedures and the information provided is designed to support site users.

3 Geophysical survey

Insight Marine Projects Ltd were contracted by the University of Exeter (Renewable Energy Group) to supply hydrographic survey services on FaBTest. The purpose of the geophysical survey was to acquire data to provide site operators and device developers a baseline dataset which encompasses the entire FaBTest site and will assist with current and future project planning and execution.

A report on the details of the configurations and results of the geophysical survey, as conducted in June and July 2014, is available in, Appendix 9 FaBTest site characteristics

The primary objectives of the survey were as follows:

1. **Multibeam Bathymetric Survey -** High resolution bathymetry using multibeam techniques to ensonify entire area within survey extents to be conducted to IHO Order 1A for Hydrographic Surveys, with particular emphasis on detection of natural upstands and debris.
2. **Sub-Bottom Profiling -** Shallow seabed penetration using sub-bottom profiling techniques to ascertain sediment thickness over bedrock within the survey extents. Required penetration was in the order of -5m sub bottom.
3. **Side Scan Sonar -** High resolution side scan sonar acquisition across the entire survey extents presented as geo-referenced mosaic seabed imagery.
4. **Sediment Sampling -** Collection of sediments samples over 12 pre-defined locations using mechanical grab techniques.

Sample results are shown in figures 1 to 3. The full datasets are available through the FaBTest databases and full support is offered from the FaBTest team in interpretation for site users. This offers an excellent resource for the exploitation of the site and is being actively used by developers engaged with the FaBTest team.

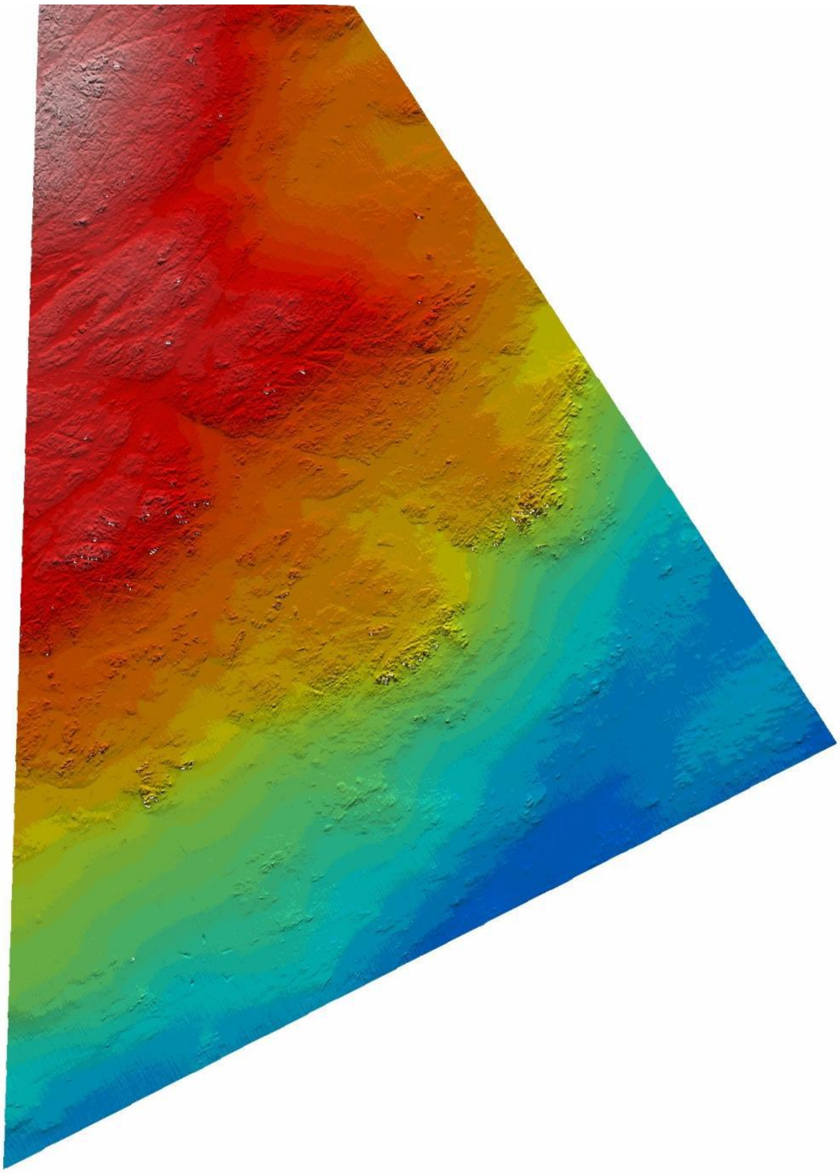


Figure 1. Multi Beam Echo Sounder coverage throughout the FabTest site

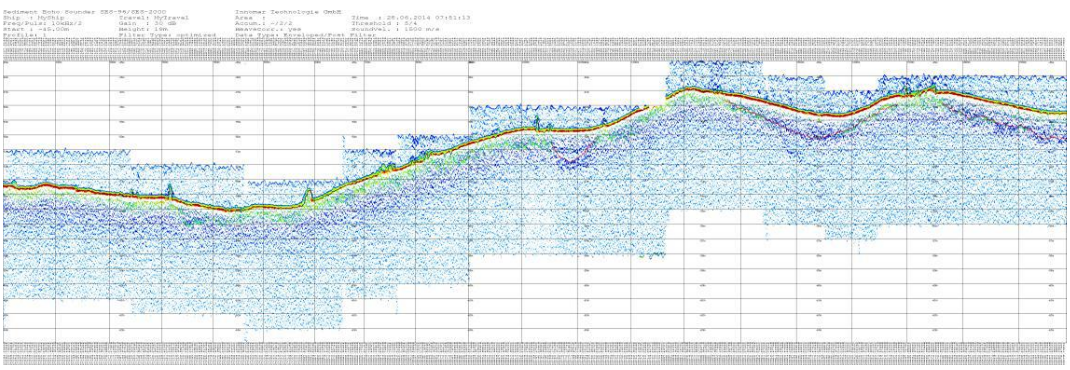


Figure 2. Example echogram showing areas of sand overlaying Unit1 reflector (red line)

Sample Ref:	4-T1H
UTC Time:	28/06/14 15:00
Recovery Easting:	357994mE
Recovery Northing:	5553474mN
Recovery Attempts:	2
Comment:	

Figure 3. Example of a grab sample taken from the site

4 Wave and current monitoring resources at a glance

Figure 4. Shows the positioning of relevant measurement equipment relative to the FaBTest site.

- Directional wave buoy stationed permanently within the site, in 40m depth since March 2012 (fig. 4).
- Second wave buoy being prepared to provide options for reducing spatial separation between measurement and devices, and monitoring spatial variability in waves across the site (Initial deployment location marked on figure 4).
- High resolution coastal wave model with very high resolution coverage of the FaBTest site itself, provides 20 year hindcast of conditions, validated against local measurements (fig. 12).
- Expertise in interpretation of these data for wave energy resource assessments, including statistical data analysis and quality control (Saulnier 2011, Ashton 2013, Smith 2013, Van Nieuwkoop 2013). Also including a specific resource assessment for the FaBTest site (Smith 2012)
- Measured tidal current profiles from ADCP deployments (see section 8.3).
- Direct links to complementary research and development streams, including the South West Mooring Test facility, The Dynamic Marine Component Test facility, acoustic monitoring and other environmental impact monitoring.

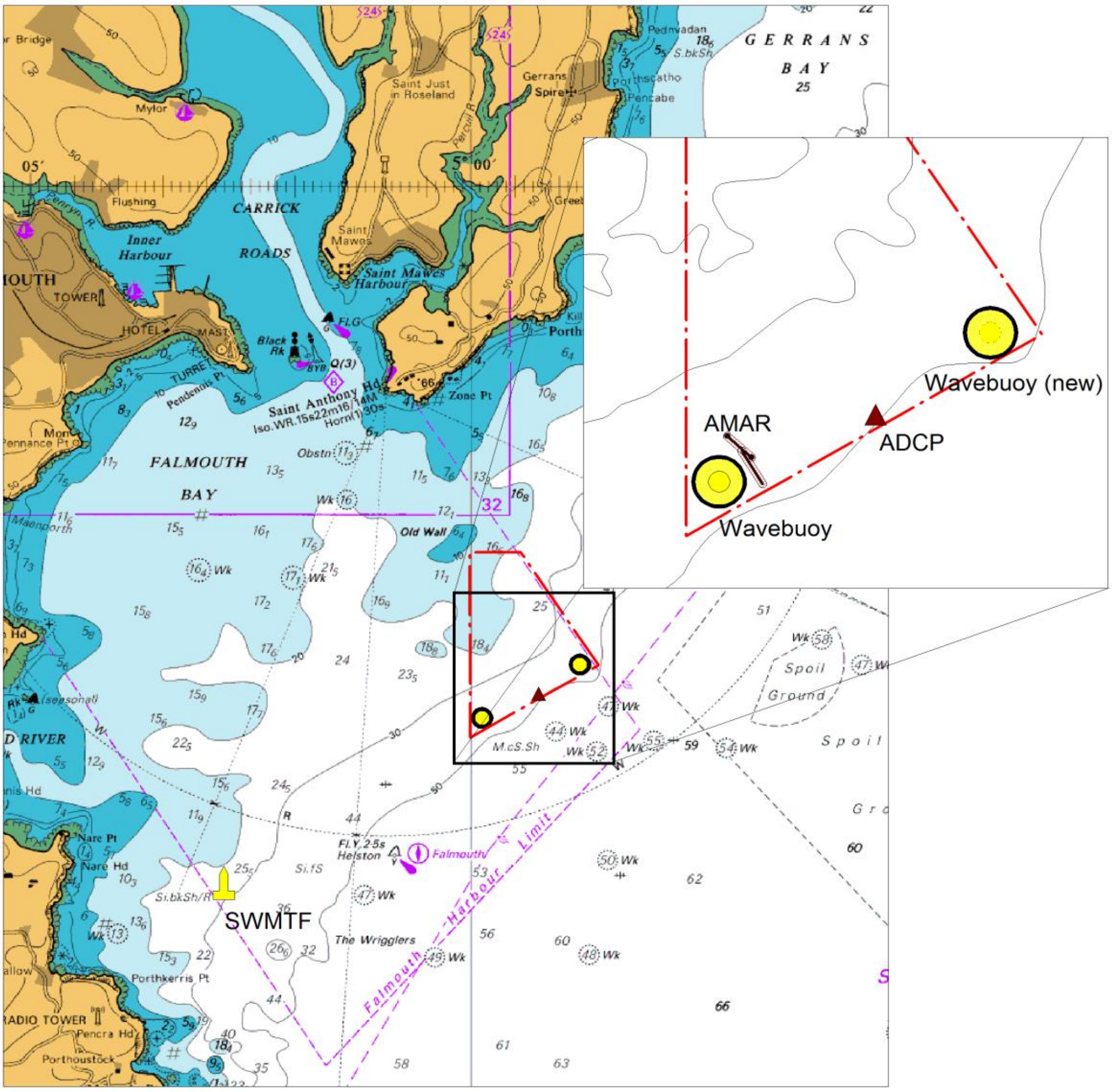


Figure 4. Measurement locations within the FaBTest site, including the excursion zone for wave buoys on their moorings. SWMTF is the South West Mooring Test Facility operated by the University of Exeter. ADCP is a seabed mounted acoustic device that measures both waves and currents. AMAR is a broad band acoustic monitoring device measuring audible wavelengths primarily for impact studies.

5 Data Storage and Presentation

All data measured at FaBTest and transmitted in real time will be transferred to the real time data store. Each month, all data will be archived. File naming protocol and file structures have been established (See appendix B).

5.1 Real time datastore

Real time data and other data sets prior to archiving will be stored on the University of Exeter data storage system (NAS). In the case of the wave buoy, data will be transferred by the wave buoy server, which will accept both radio data and GSM data, all of which are transmitted directly onto University of Exeter networks. On the server(s), low computational requirement (fast to run) Python scripts will be run providing initial data validation and appropriate data type conversions such as re-formatting time/date stamps, including limited quality control. This will then transfer the data to both the real-time data store and the University of Exeter long term storage.

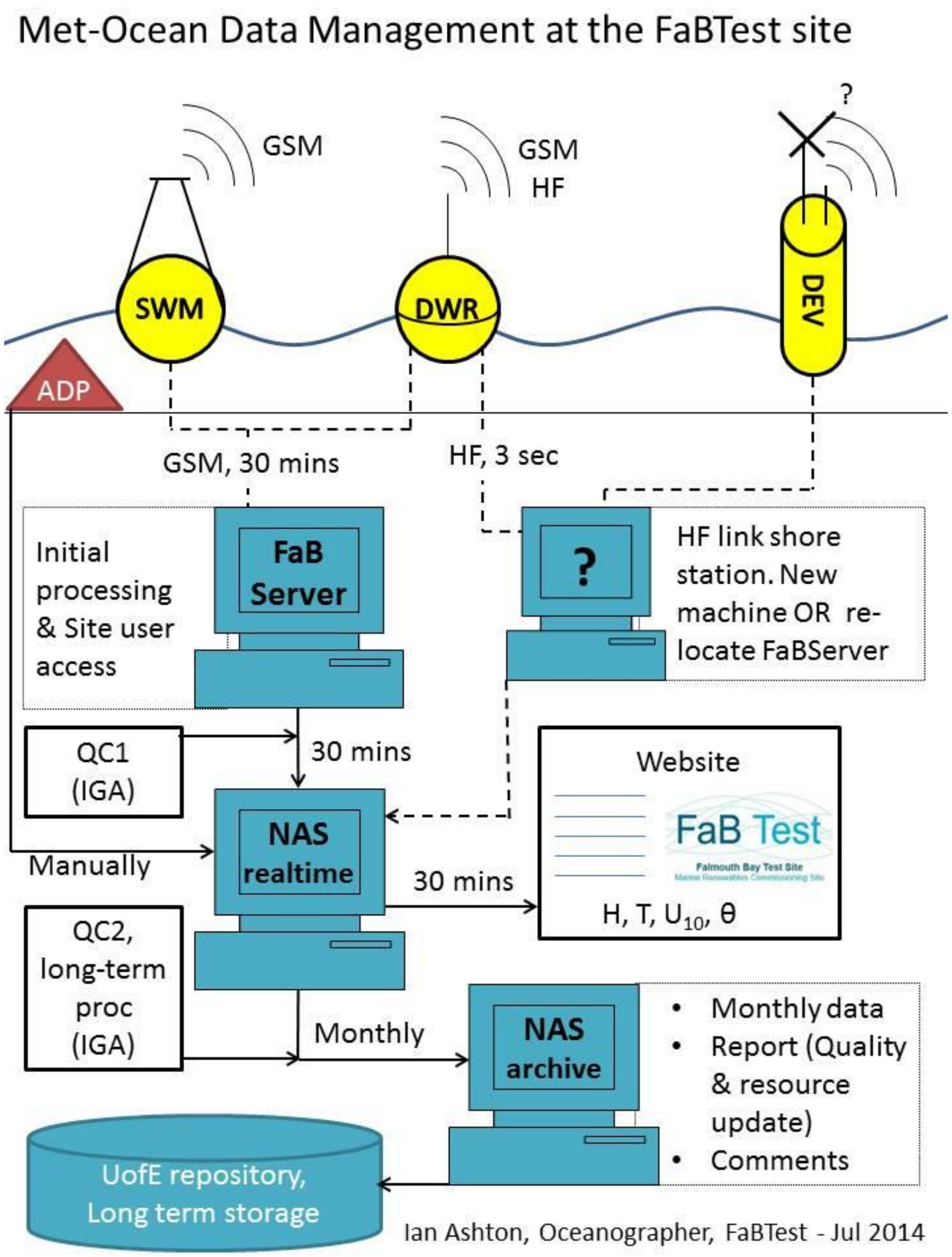


Figure. 5. Oceanographic data flow for the FaBTest site showing how data are transferred from the instruments through to long term storage, highlighting user access.
DWR refers to the Datawell waverider buoy. SWM refers to the SeaWatch Mini II wave buoy, ADP refers to the ADCP sensor, and DEV refers to devices on test, which may wish to have data

5.2 Archive database

Each month, data will be collated in the archive database. This will incorporate all data gathered at the site during each month, including data that are not gathered in real time, such as the ADCP. It is also a target of the team to incorporate concurrent research to provide results from a monthly run of the wave model.

Detailed quality control will be performed using automated programs developed by the University of Exeter researchers. These will produce a report on the quality of the measured data and where relevant, an intercomparison of the data sources. In addition, metadata including the instrument used, the permissions for re-use and any relevant information will be stored. This is an essential step in ensuring the continued usefulness of this data.

5.3 Data provision to developers

For developers and collaborators, data will be accessed through the website which serves as an information hub and a data portal to the real time data store. It is accessed through password protected accounts, set up through the FaBTest team (fig. 6). Site users will be able to nominate collaborators, such as marine operations providers in order to provide direct access to the latest data. Once developers have logged into the website, they will have access to a download page where they will be able to download the raw data (stored as zip files).

The website hosts a secondary MySQL database locally, this is used solely for the purpose of displaying live data. The website receives selected live wave buoy data from the server every 30 minutes through the use of a Python script which parses the appropriate data, re-formats the date/time stamp and uses SQL INSERT statements (via a SSH tunnel) to send the data. Every time the page is loaded in a web browser, it query's the local database for the most recent update which in turn automatically updates and displays on the website.

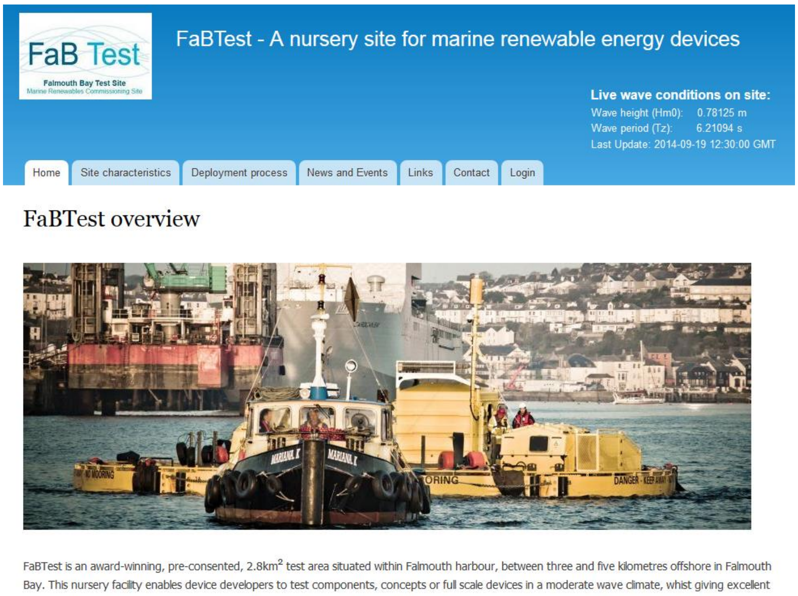


Figure 6. Screenshot of FaBTest.com website displaying the live wave buoy data (Top right)

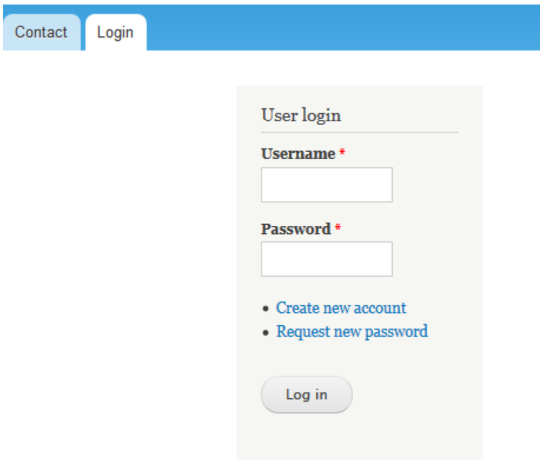


Figure 7. Screenshot of FaBTest.com website login section for access to controlled database.

In addition, procedures developed in ongoing and previous research are being automated to provide monthly updates to key analyses for developers:

- Quality control of raw data sets
- Intercomparison of model and in-situ data, providing a report on model performance during the month
- Updating long term characterisations
    - Resource at site
    - Extreme analysis
- Specific requirements from developers

All of the above are being integrated into a suite of programs developed using Matlab that produces a monthly bespoke report for each developer engaged with FaBTest. Through research projects and in response to requests from developers, new routines have been developed that can be adapted to provide analysis of site data and incorporated into the report function. This process means that the group can respond to the specific needs of each developer. As an example, SWEL Ltd are particularly interested in wavelengths. Following a period of consultation, a custom Matlab program was developed to provide key information about wavelengths at site from the data gathered to date. This has been supplied to SWEL as a report and the same analysis will be automatically included in each report about site conditions they receive (although updated with the latest data). This supplements their access to the real time data and provides developers with critical information to either optimise lessons learnt from testing across each month or to plan deployments in the future.

Work to date

- Setup wave buoy server
- Establish routines for processing and transferral of real time data from SWM
- Develop routines for initial QC processing load data
- Develop database structure and initial QC
- Develop website and display of real time data

Work ongoing

- Install and set up DWR
- Develop processing for DWR data
- Automate processing for wave data

5.4 Recording data on a device during testing

The ORE group have considerable research experience in monitoring devices and components during operation and testing. This is supplemented through FaBTest work and supports useful interactions with developers. Key considerations where the group offer advice include synchronisation between device sensors and other data sources and designing a measurement campaign to gather useful data, particularly those regarding mooring loads and design.

For integration into the university databases, when developers gather data it should be separated in different files depending on their acquisition frequency. The files should be named by their date for example with the following format YYMMDDHHmmssm_ext with YY the year, MM the month, DD the day, HH the hour, mm the minute, ss the second and ext the extension of the files. The files can be compressed into a single zip named for example YYYY_MMDDHHmm.zip. Where these are passed to the real time data store, they will be stored in a directory indicating the date of the file YYYY/MM/DD.

5.5 Device data acquisition set-up

Data can be delivered and received to and from the FaBTest site by an antenna placed on the roof of the ESI building in Penryn campus, University of Exeter, TR10 9FE. Whilst the FaBTest site manager can arrange for access to the site and to the University network for Internet access, it is the responsibility of the Marine Technology Developer to provide the necessary equipment for data transferal. Due to the risks associated with working on roofs, any equipment to be deployed on the roof will be installed by the university estates team.

The bearing of the centre of the FaBTest site from the ESI building roof is 124.5° at a distance of 11.89km, as shown in Figure 1, and hence declination of 0.76° (1.32%).

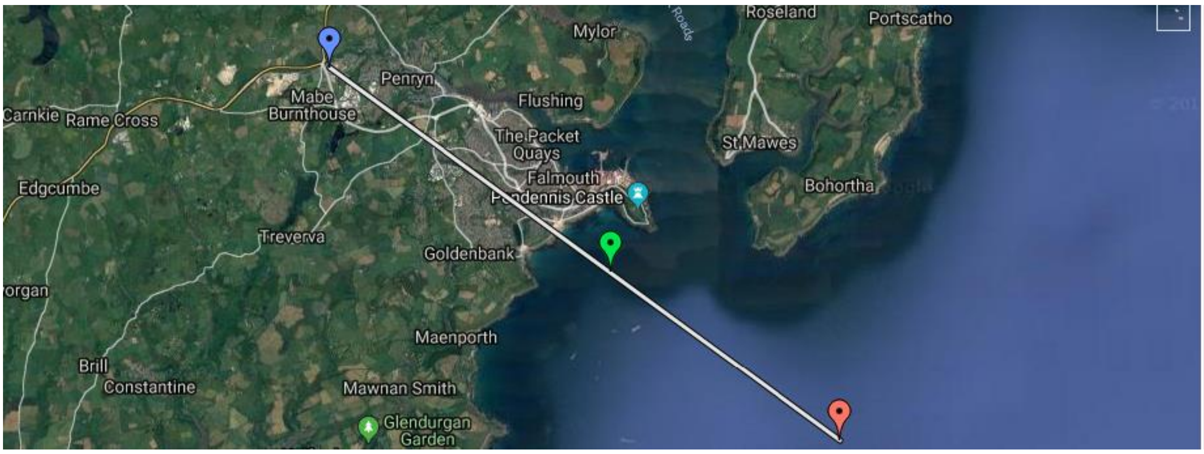


Figure 1: Direction from ESI Building, Penryn Campus, Falmouth to Centre of Falmouth Bay Test Site

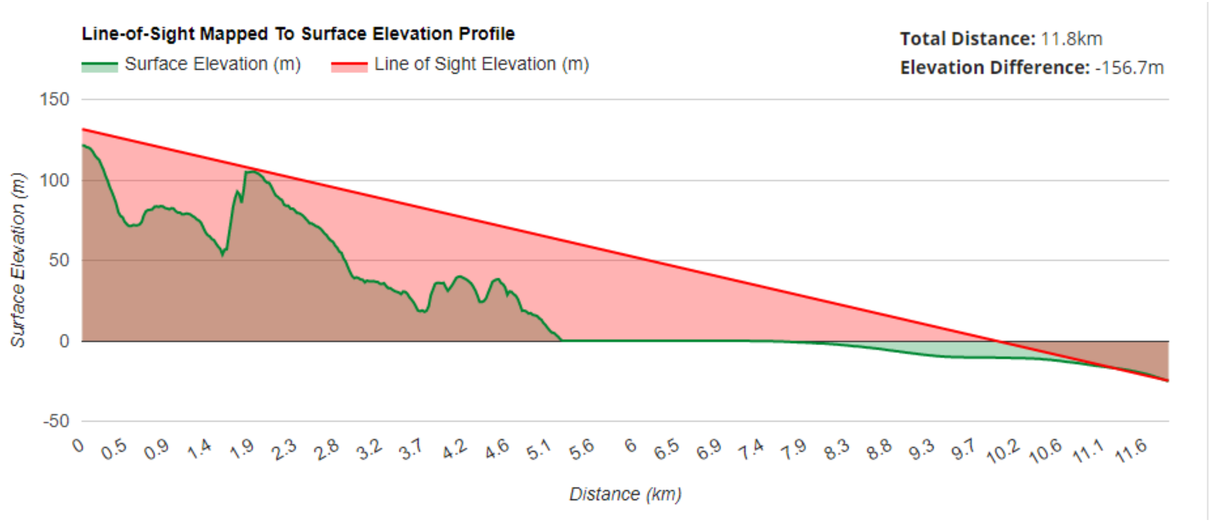


Figure 2: Effective Line-of-Sight from ESI Building, Penryn Campus, Falmouth to Centre of Falmouth Bay Test Site.

5.5.1 VHF

VHF radio frequency provides the most reliable contact with devices deployed on site, with a link connection rate of 81.92 bits per second. As an example the university wave buoy transfers approximately 100KB of 1Hz wave data every 4 seconds over VHF to a server where it is also backed up. Further to this the wave buoy transmits an approximately 500KB package of data every half hour, which mitigates any connectivity issues that may have occurred between the buoy and onshore antennae.

Figure 3: Wave Buoy Antenna, as set up on University Building. View to site (South East).

To set up your VHF receiver station you will need:

- VHF Antenna
- Antenna mount
- Antenna mount brackets
- At least 25m of cable (antenna cable)
- RF receiver
- Power suppy
- Serial cable/additional ethernet cable
- VPN/Router
- Ethernet cable
- Power cable x2
- Tools for installation

Figure: images of current antenna set up

You will also need to provide us with:

- Your static IP address.
- Ports / Protocols required for VPN remote access
    - E.g. Source port, source IP, destination port, destination IP.

We will then provide you with details including:

- External facing static IP to connect to the device

5.5.2 Wi-Fi

Wi-Fi frequency (i.e ~2.4-5GHz / 5GHz) data can also be transferred, from FaBTest via a Wi-Fi relay station at HM Coastguard Station on Pendennis Point, Falmouth. A Wi-Fi receiver station will be present at the University. To complete this setup you will need to provide a compatible Omni directional antenna (aboard your device). Wi-Fi frequency antennae tend to be more directional and therefore connectivity can be an issue on highly dynamic structures, however when a connection is made high volumes of data can be transferred at speed.

Figure: images of current antenna set up

You will also need to provide us with:

- Your static IP address.
- Ports / Protocols required for VPN remote access
    - E.g. Source port, source IP, destination port, destination IP.

We will then provide you with details including:

- External facing static IP to connect to the device

5.5.3 Risks

Please carefully consider the risks to effective data transmission, with appropriate mitigation and contingencies. Weather, device stability and reliability of power should be primary considerations. For example:

- Power outage: Developer Device, Relay station, University building, Developer base

- Wi-Fi outage: Developer Device, Relay station, University building, Developer base
- Weather: Rain, Cloud, Device dynamics

University power supply to data storage is provided by UPS (uninterruptible power supply) and multiple data backups are employed. The relay station (Wi-Fi only) will not store any data, however in the event of power outage will not be able to transfer data.

Equipment is kept in a location with restricted access, however for increased security you may wish to provide a lockable cabinet, within which to store your data acquisition equipment, to be accessed only by you.

5.6 Data sharing

Data gathered by the University of Exeter at the FaBTest site will be covered by the Offshore Renewable Energy group data protocols. This system can incorporate both data owned by the University and third party data. Within the system, the group have named a group leader (prof. Lars Johanning) whilst a data manager and data supervisor will be allocated for each data set. At the outset of a project, data must be classified into one of three categories, defined in terms of their accessibility rights (see below). Where collection is within a research project, this must reflect the University's legal requirements for the dataset, which are established at the project outset. This process is the responsibility of the PI (for UoE). Where the data arise from a private agreement, or are entirely owned by the site user, they will automatically be classified as commercially sensitive data unless instructed otherwise.

5.6.1 Data Classification

1. Open access data (OAD) – No limitations are placed on the use of this data by third parties. However, applications for these data during a live project, must be made using a University of Exeter data access form signed by the Group Leader and third party applicant. This form specifies the proposed use. Efforts should be made to ensure the third party user is able to use the data effectively for the proposed application. Data should not be released if the Data Manager, Data Supervisor, or Group Leader feel that the intended use, or outcome, may be misleading, inappropriate, or damaging to FaBTest or partner organisation.
   Once the project is closed, the full dataset will be reviewed, and transferred to the institutional repository, with any embargo set out by the funding body respected.
2. Controlled data (CD) – This includes data that are owned by FaBTest/UoE, and do not contain a requirement for open access. These data should not be released without a data agreement form signed by a member of the UoE Legal Services Office, the Group Leader, and the relevant third party applicant.
   Once the project is closed, the dataset will be uploaded to the institutional repository with an indefinite embargo period (forever).
3. Commercially sensitive data (CSD) – Where data are collected with direct relevance to a commercial application, they must be considered commercially sensitive. Where this is the case, the Group Leader and Data Supervisor must be informed prior to collection. Access protocols will limit the viewing of these data to the relevant Data Manager and contractually associated staff. If a request is made to share these data, it must be taken forward to the commercial partner, and the release of data will be subject to their authorisation and/or the

University's legal obligations. The contact details for the commercial partner must be kept up-to-date.

Once the project is closed, the default actions will be to transfer the dataset to the institutional dark archive unless this contravenes the agreement with the commercial partner, which takes precedence.

Third party data can be stored, although they must be supported with clear documentation to identify source and ownership, as well as being classified as per the categories above.

No private data may be stored, all data must have direct relevance to FaBTest.

6 Data collection

The Offshore Renewable Energy group, led by Dr Lars Johanning have a demonstrated strength in applied research to support offshore energy technology development. Within this team, there has been an historic strength in resource assessment, particularly for wave energy. Developed under Professor George Smith, the group were instrumental in developing standards for the measurement, processing and analysis of wave data for the assessment of wave energy devices (Ingram et al. 2011). To date, the group continues to measure environmental data, develop understanding of resource assessment, and inform best practice for offshore energy industries.

Initiated in support of the Wave Hub, the University of Exeter have developed a regional wave model has been using the coastal wave model SWAN. This high resolution model provides wave parameters across the region, with very high resolution nested grids covering the FaBTest site. The model has been run in hindcast mode to provide a very high quality data set spanning 20 years of historic data, validated by in-situ measurements across the region (Van Nieuwkoop 2013). This has been applied to the definition and characterisation of the wave conditions at the FaBTest site, providing valuable data for site developers. This is underpinned by the ongoing research and development of this model with relevance to resource assessments, and impact assessments in the continued development of best practice for the industry (Ashton 2013, Smith 2013, Vickers 2013)

A directional wave buoy has been operational on site since March 2012 (fig. 4). This returns wave parameters every 30 minutes as well as measuring the surface position of the buoy at a frequency of 2Hz. The outcome is a time series of the wave profile and a directional spectrum every 30 minutes. Data retrieved are of very high quality and the time scale of two years provides a wide range of measured conditions including significant storms during the winter 2013/2014. This allows a detailed characterisation of the conditions and supports validation of wave models.

A further wave buoy has been purchased to consolidate the program of long term monitoring (fig. 4). This will also offer the possibility of real time (every 5s) wave monitoring, reduced separation between measurement location and device during testing and support research into spatial variations in waves across the site. This added flexibility could incorporate particular needs for developers, or will support short term research projects where intensive data collection is required (e.g. Ashton 2013).

ADCP units measure the current through the water column, providing a profile of current speed and direction. These have been deployed at the FaBTest site to characterise the current regime at the site and further measurements are being planned. Real time communication is in development although the nature of the site and the instrumentation make this a difficult proposition, albeit with significant potential benefits to device monitoring at site.

6.1 Wave Buoys

Two directional wave buoys are available to the FaBTest site. These buoys are designed to follow the sea surface motion. Therefore, measuring the buoy motion provides an exact measurement of the water surface, which can be used in turn to derive a directional measurement of the surface wave field.

1. The Seawatch mini II (SWM) is a commercially available wave buoy built by Fugro Oceanor. Accelerations are sampled using solid-state accelerometers on three separate axes. When combined with simultaneous heading and tilt readings, accelerations are resolved to heave (vertical), east and north axes. These are then double-integrated to give a time-series of positions on these three axes. A description of this process is available in the instrument manual (Sanmuthagan 2009).
2. The Datawell waverider buoy (DWR) has been established as the industry standard tool for in-situ wave measurements. It uses a gravity stabilised platform to provide a measure of vertical acceleration unaffected by other motions. A time-series of motions in the other two axes are derived through accelerometers, as with the SWM. Again, this processing is performed on-board

The wave buoy, as a moored platform, requires that a restoring force be applied from the mooring. Joosten (2006) provides detailed discussion of mooring design floating wave buoys, which are designed by the manufacturers to allow the buoy to respond unhindered to wave frequencies, whilst resisting tidal flow and drift forces to keep the buoy on station. Nevertheless, the mooring remains a potential source of errors in wave data, particularly surface following buoys. The group have undertaken considerable research and development to optimise the moorings for the FaBTest site and validate their readings. The presence of multiple wave measurements represents a rare opportunity to derive independent error estimations which will be published with the monthly archive data.

6.1.1 Buoy data

Both wave buoys output data at different levels of processing. Processing is done on board and each of these levels is output in real time to the real time data store. Subsequently, during archiving, the processing is repeated using routines developed by the research group. This incorporates QC and allows more control over the process to maximise consistency of wave data between sources and has been shown to remove errors and discrepancies, producing a more robust data set. Table 1 shows the levels of data and how these vary between technologies. Time-series, Spectrum and Summary parameters are all available in both real time and archive databases.

<table>
<tr><th></th><th></th><th>SWM</th><th>DWR</th><th>ADCP</th></tr>
<tr><td rowspan="2">Raw</td><td>Parameter</td><td>Acceleration</td><td>Acceleration</td><td>Orbital velocity</td></tr>
<tr><td>Samp freq</td><td>4Hz</td><td>4Hz</td><td>2Hz</td></tr>
<tr><td rowspan="2">Time-series
(fig. 8)</td><td>Parameter</td><td colspan="2">buoy positions in the vertical, east and north directions</td><td>Orbital velocity in V, E, N</td></tr>
<tr><td>Samp Freq</td><td>2Hz</td><td>1.28Hz</td><td>2Hz</td></tr>
</table>

	Record length	17mins 04sec	30mins	17mins 04sec
		Measurement commences on the hour and half hour based on coordinated universal time (UTC).		
Spectrum	Parameters	Spectral energy density and directional distribution, S(f)D(f,θ)		
	Freq range	0:0.5Hz	0:0.5Hz	0:1Hz
	Freq resolution	User defined		
Summary parameters (fig. 9)– Produced through analysis of the spectral data or time-series data. A full set of parameters are available for each sensor which, along with the procedures for data processing are described in more detail in section 5				

Table 1. Comparisons between data types for wave monitoring equipment used at FaBTest

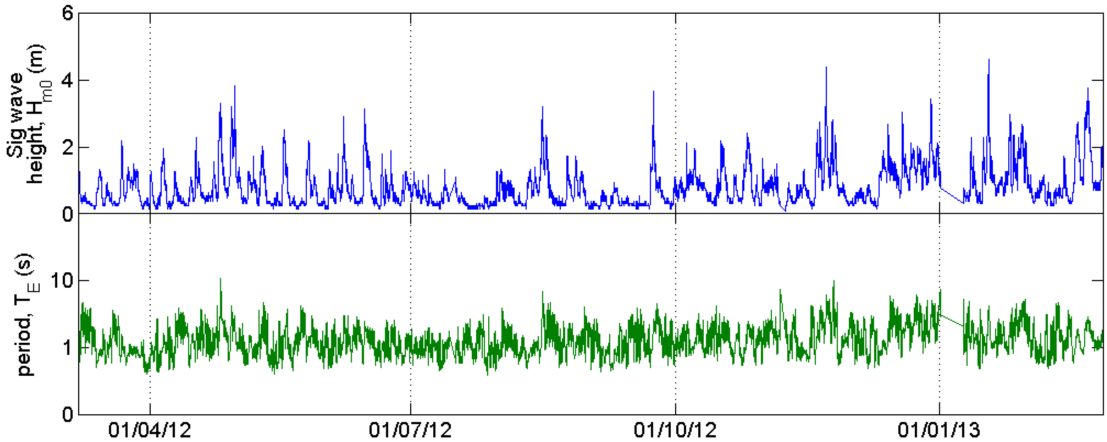


Figure 9. Time series of summary parameters, significant wave height and wave period from the Seawatch mini II buoy deployed at the FabTest site.

6.2 ADCP

An Acoustic Current Doppler Profiler (ADCP) uses Doppler shift to measure the speed of individual particles in the water column. This raw data set is processed by proprietary software to provide measurements of orbital velocities (waves) and mean currents (tidal flows). The ADCP is installed on the seabed and the research group are experienced at positioning them close to floating structures. In this case, the AADCP must be sited with enough distance to avoid the measurements to be affected by the mooring.

One ADCP unit is available for FaBTest. Section (7.3) below describes results and analysis from an initial deployment to characterise currents at the site.

Data are recorded at 2 Hz for a defined number of bins through the water column. The number of bins is variable and can be defined relative to the required outcomes. More bins creates more data and the deployment duration is shorter. However, the extra detail may be of value to the end user. The same situation arises with the temporal resolution of measurements. Frequent or continuous measurements create more data. However, continuous data is highly recommended for monitoring extreme loads.

For wave data, 2048 data points at 2Hz are recorded (17.067 minutes). Processing follows that presented in appendix A. Quality control follows that presented for wave buoys

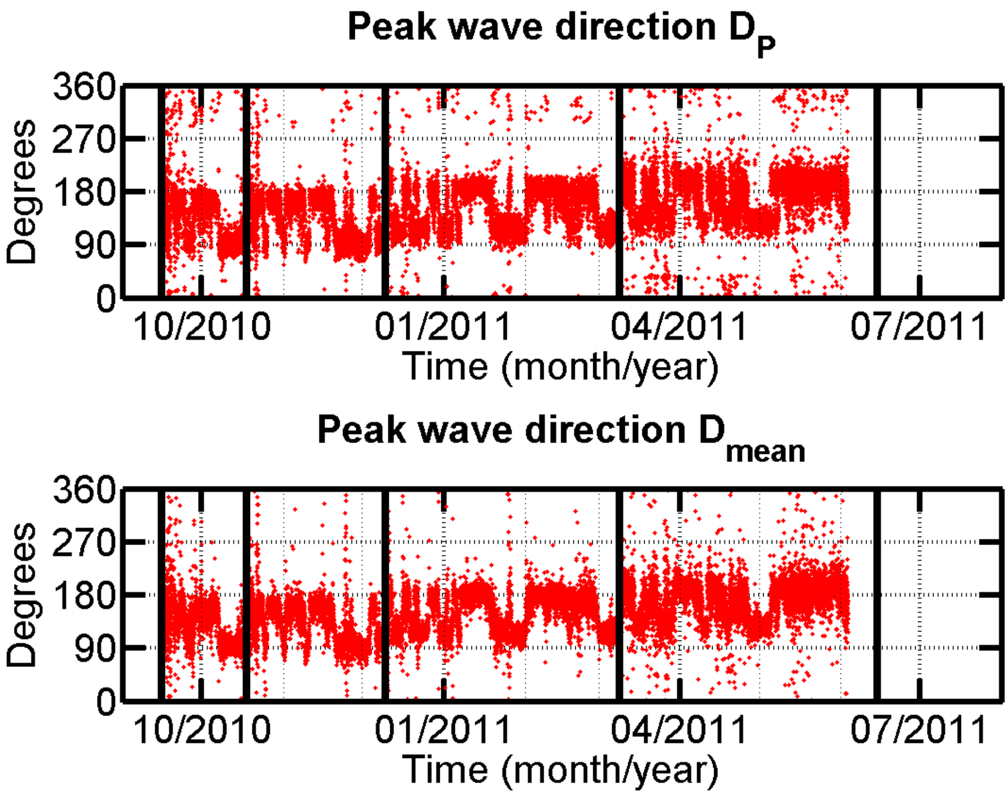


Figure 10. Wave directions between the different ADCP deployments during SWMTF deployment. Vertical black lines indicate ADCP re-deployment

Of particular importance to ADCP measurements are the direction as this can be affected by the calibration of the compass. In previous work, the group have developed a procedure for the correction of the compass, supported by independent compass measurements. Figure 10 shows an example of this phenomenon.

Current data are quality controlled to identify spikes or rogue readings through a range test (values above or below a given threshold are queried). For the FaBTest site, these thresholds have been set based on freely available chart data. However, the values will be updated should they be exceeded by a valid result. As such, the thresholds continuously evolve, and highlight unusual or extreme data as well as errors. Interpretation must take this into account.

Also taken into account are complications within the surface layer, a thickness of 5-15% of the total water column. Here, sidelobe reflections of the acoustic beams can compromise the measurements. The maximum current magnitude C_{Mag_max} is evaluated in the bins below the surface layer. The chosen current direction C_{Dir_max} is the direction measured at the bin of maximum current magnitude.

6.3 Wave Model

The University of Exeter have developed a high resolution regional wave model using SWAN (Simulating WAves Nearshore) (Booj 1999). Run across a high resolution grid, the model predicts the sea state variability in the region (fig. 11). SWAN accounts for depth and current-induced refraction and represents processes that generate, dissipate or redistribute wave energy. These processes are represented within SWAN as source terms, which are quantified by their effect on the spectral energy values. Processes represented include the deep water processes of wind input, whitecapping dissipation, quadruplet nonlinear interaction and the depth-limited processes of bottom friction dissipation, depth-induced breaking and triad wave-wave interactions. User-induced source terms can also be applied including vegetation, or obstacles introduced to the model domain.

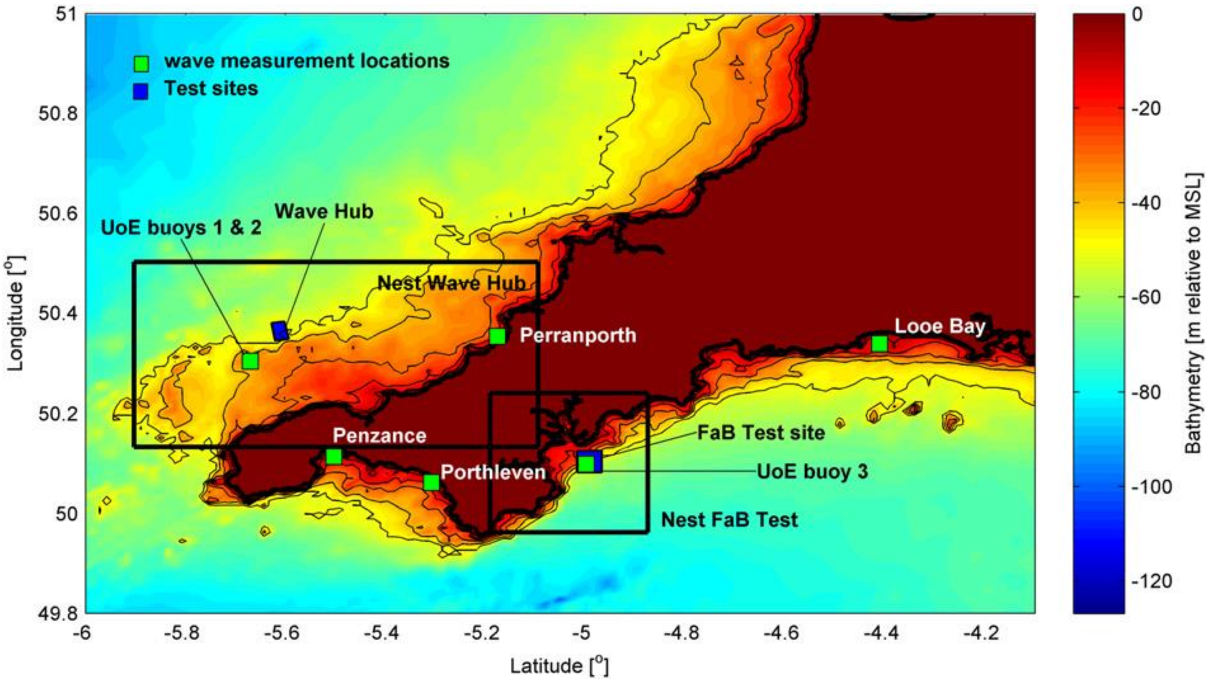


Figure 11 Regional model domain showing nested high resolution grids over FaBTest (from Van Nieuwkoop 2013)

The bathymetry for the wider model and the 100m nest was constructed from data interpolated from Marine DigiMap, whilst the high resolution grid was constructed from multibeam sonar data collected using a WASSP system mounted on the University of Exeter's research vessel. Spectral wave data were used as boundary conditions, reconstructed from partitioned data from the ECMWF global wave model. Wind conditions across the grid were supplied by the Met Office model output, but no water level variations or currents have yet been taken into account.

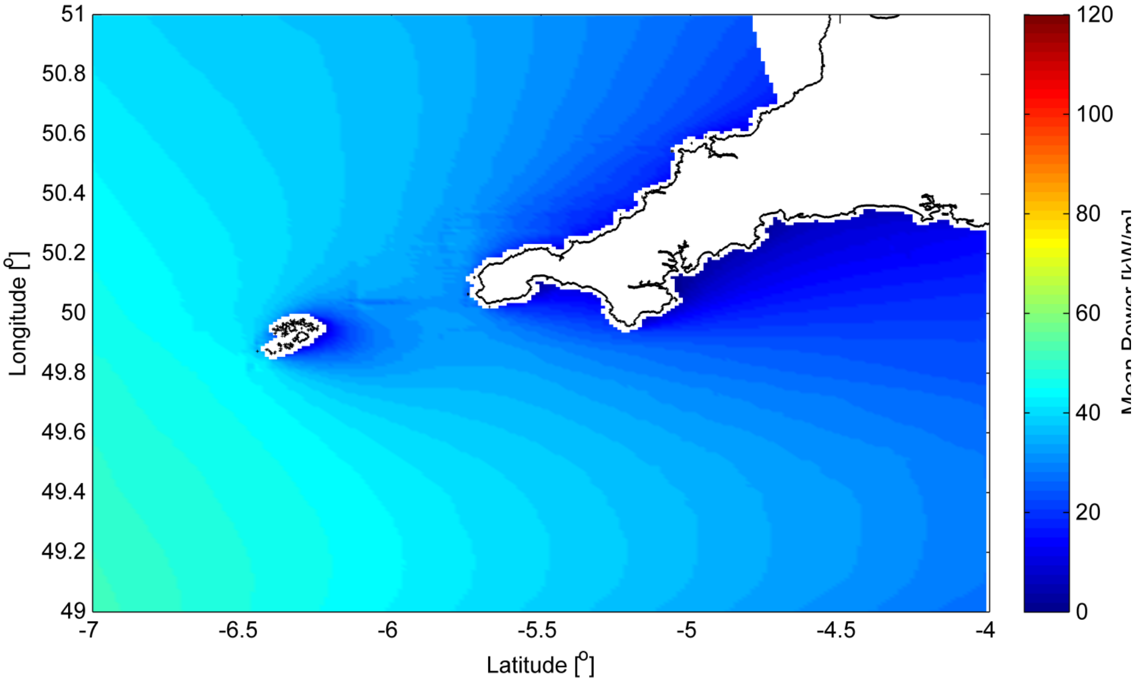


Figure 12. The average wave power P_T over a 23 year wave model hindcast for the region including the FaBTest site.

6.3.1 Model development

The regional model is under constant development. Model outputs are reviewed in comparison with ongoing in-situ data collection, and work is underway to automate this process. Automatic running of the regional model will allow regular reporting on performance when compared with in-situ data. Prior to this process, sensitivity analyses are underway for the grid size, and the inclusion of tidal changes into the model.

Initial examination on a simplified model covering a subset of the domain reveals the effect of grid resolution within the model (fig. 13).

Ongoing projects at the University have seen the availability of high quality tidal model data across the model domain. Integration of this data has the potential to increase the accuracy of wave model outputs across the region. The effect on data for FaBTest is likely to be smaller than at coastal locations, or zones with high tidal flow and preliminary work to produce sensitivity analyses are underway to reveal the extent to which outputs are changed.

When additional data for wind and current are included at high resolution, the volume of data and calculations can cause numerical problems to appear. Some numerical artefacts are observed which affect data quality, and in certain cases, the model fails to converge. Thus, the definition of the model setup is a balance between the computational requirements and accuracy. Utilising the computing cluster at the University, the group are able to maximise the computing capabilities and produce very high quality model products. To this end, the group aspires to retain flexibility in its programming to ensure that the systems developed will be optimised for each data set incorporated in order to provide the best possible data to site users.

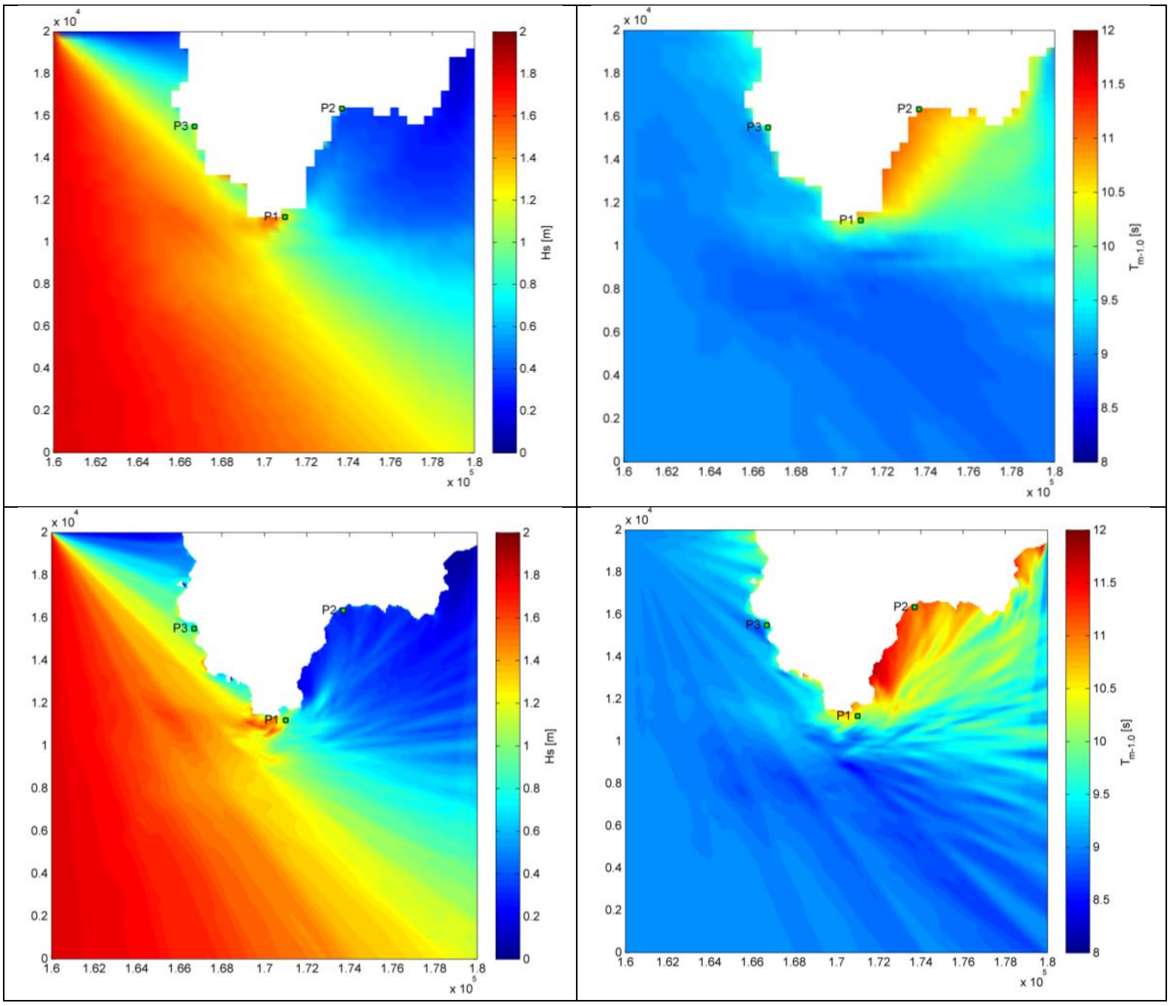


Figure 13. Selected results from a sensitivity analysis conducted to investigate the effect of model gridresolution on results and to optimise model setup.

6.4 Mooring loads

Research to date has drawn both from the South West mooring test facility and the Bolt II installation at the FaBTest site (fig. 14) to develop procedures for the assessment of mooring loads.

The SWMTF was designed to enable component testing of mooring systems acting in a coupled system with a buoy. The data gathered from the test facility can be used to calibrate numerical models, enhance the physical understanding of the coupled behaviour and obtain understanding of component loading and deterioration. The buoy has been designed in house and work to date has led to a defined procedure for deriving robust data for users of the facility. Research by the FaBTest team have developed these procedures for the assessment of mooring loads for floating devices.

Figure 14. Fred Olsen Renewables, Bolt II device on test at FaBTest.

The Fred Olsen Bolt II was also equipped with instruments to monitor mooring loads. Benefitting from a close collaboration with Fred Olsen Renewables, the research team were able to further develop methodologies for monitoring and predicting loads on floating structures, with application to tests on site.

Ongoing work by the FaBTest team (Harnois, 2014) have applied data from axial load cells that record the forces applied to moorings to the identification of extreme mooring loads (see section REF). Initial data acquisition recommendations have been developed for site users.

- Initially, the pre-processed data (i.e. mooring load, GPS position, HS...) are corrected as follows,
  - If the mean mooring load (for a dataset) is negative, then these load data are removed.
  - The data were also removed after visual inspection if the maximum load was too high and isolated.
  - If the mooring load data are drifting, a moving average is applied to the mean load, removed to the drifting signal (minimum, mean or maximum load), and the mean of the other mooring loads (on the other lines) during this interval is added to the signal. The number of points for the moving average is determined by trial and error, in order to remove the global drift of the signal but not the local variations due to tide or storm. After corrections, the data which could not be corrected are manually removed.
- The recommended acquisition frequency of 20 Hz and a resolution of 1 kg is optimum to derive extreme mooring loads.

- On board GPS records device position at 10 Hz. Data are converted into meters, taking the device target position as the reference (0,0,0) position. The quality of the GPS data is also recorded.
- The buoy is also equipped with a compass, accelerometer and gyroscope. The aim of these instruments is to obtain a more accurate position of the floating structure. However, uncertainties appeared during integrations of the linear acceleration and angular velocity data to obtain position and angle. These data should be used with caution

Figure 15 Example of loadcells: a) axial and triaxial loadcells used at SWMTF; b) axial loadcell used on Fred Olsen LifeSaver Bolt 2 device installed at FaBTest

These recommendations have been combined into an in house software tool to access SWMTF data (fig. 16), which can be adapted to the needs of developers. Section (8.4) below, details research undertaken to predict extreme loads on floating structures based on SWMTF trials. This work is directed to help provided developers with robust estimations of this critical parameter.

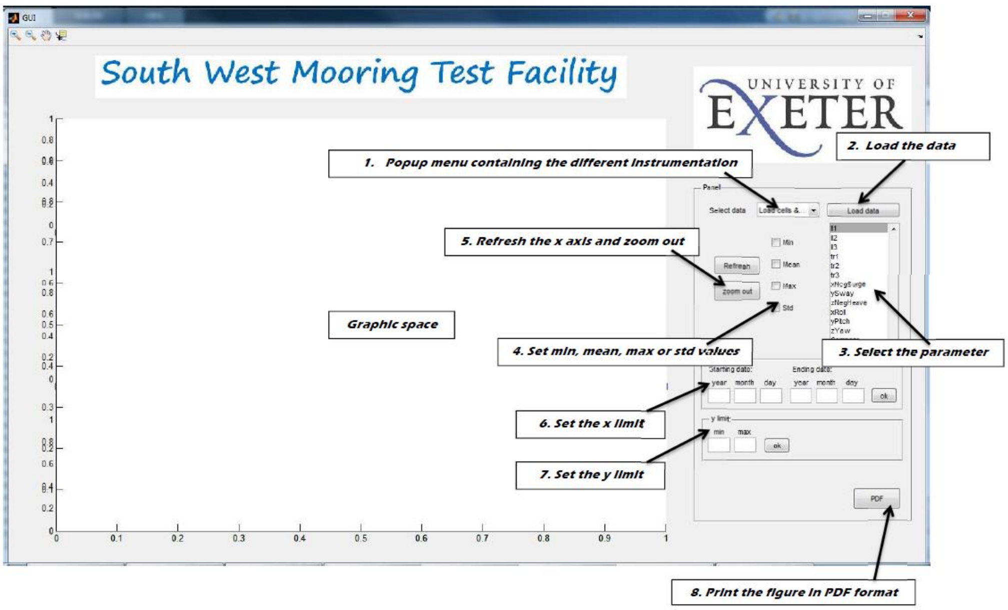


Figure 16. A screen shot of the in house software designed to facilitate reading and interpretation of SWMTF data.

7 Data processing

Initial, processed data from wave buoys will be published to the real time data store where developers can access data directly and from which data are drawn to populate the website. Quality Control (QC) and analysis will be applied during the monthly archiving process to these data as an integral part of the suite of Matlab processing programs described initially in section 5.3. As such, results will be included in reports to developers, ensuring they can make an informed assessment of conditions during the month.

7.1 Quality Control – Wave Data

Quality control checks applied here are based on a draft standard on the subject (Tucker, 1993), and follow recommendations in relevant protocols (Smith and Taylor 2007, Pitt 2009 & Ingram et al. 2011). The literature stresses that most problems are more readily identified through examination of the spectrum resulting from the entire record than tests applied directly to the time-series.

Flag value	Test	Test purpose
10	$-4\sigma(\eta) < \eta(t) < 4\sigma(\eta)$	For seas where individual wave heights follow the Rayleigh distribution, the probability that a normalised wave crest, $h_c/sqrtm_0$, will be below x is given by, $P_N(x) = e^{-N_z e^{(-1/2x^2)}}$ From this, the expected frequency of exceedance of a crest height of $4\sqrt{m0}$ is 0.03, and this flag would be expected to be raised in 3% of error free records [Tucker and Pitt, 2001]
20	$S > 5\sigma(S)$	$\sigma(S)$is the standard deviation of the steepness values.
30	$\eta_i = \eta_{i+1:3}$	Repetition of the exact value in the time series indicates a sensor failure

Table 2. Quality control tests applied to the time-series of surface waves (see also figure 17)

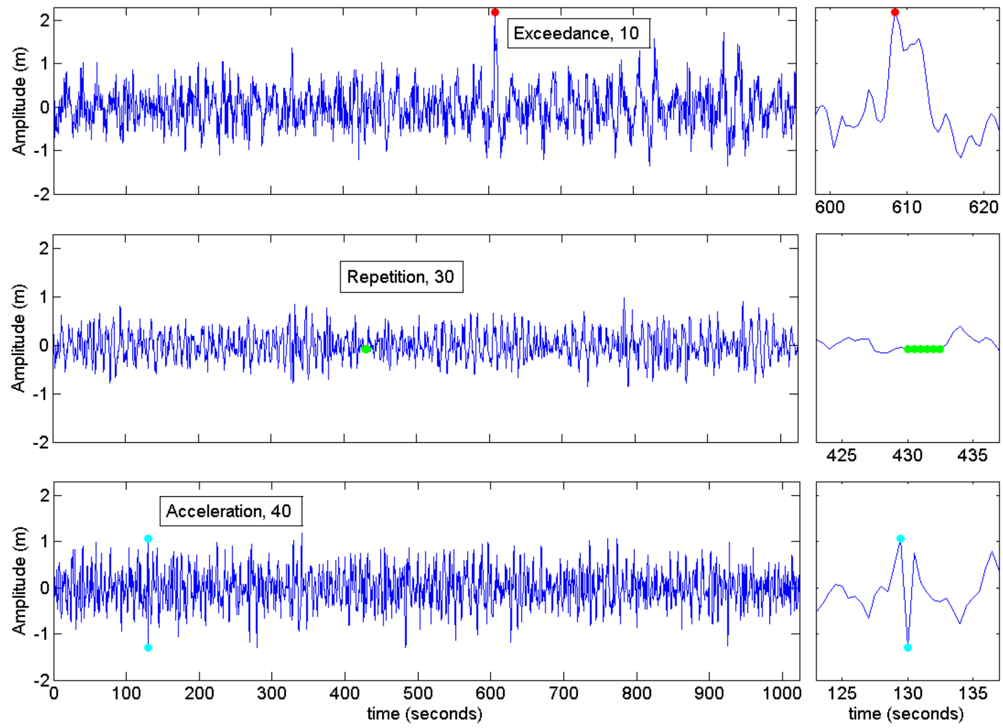


Figure 17. Example errors highlighted in the raw wave data, along with the value assigned in the error flag

After spectral analysis, each record consists a set of parameters calculated on-board the buoy, a time-series of positions and a one dimensional spectrum. The quality control function performs a series of tests on the time series data (tab. 2) and further tests on the spectral data (tab. 4). There are two outputs from the quality control function. The first is an error flag for each set of values in the time-series record, and the second is a vector of up to 6 error flags which refer to the different tests relating to the entire record. Many of the tests performed are statistical in their nature and highlight records which have properties that can be considered unusual but not impossible. Therefore, care should be taken before discarding or ignoring any record. It is not the aim of the process to eliminate extraordinary sea states, and the systematic removal of extremes will alter the statistical properties of the data sets. However, the same is true for erroneous records within the data set. Further functions can be used to plot the time-series and spectrum for any record where an error is identified. Visual checks of flagged data are considered a vital part of the quality control procedure and care should be exercised before discarding a record completely before the time-series and spectrum have been visually checked. It is worth noting that the deployment of multiple sensors has the potential to improve this process. Unusual records can be compared to simultaneous records from other sensors to provide an extra indication of the validity of their occurrence.

Flag value	Test	Test purpose
1	$Tz_{TS}/Tz_S \geq 1.1$	This indicates errors in low sea states due to the heave resolution causing small waves not to cause zero crossings.
2	$R_s(LF) = \frac{S(0.0146)+S(0.0195)+S(0.0244)}{3S(f_{peak})}$	The critical value of this ratio depends on the location however [Tucker, 1993] recommends 2% for time-series of surface postitions, any exceedance indicates low frequency noise which is typical of a faulty sensor.
3	$S(f) = 0.0081g^2(2\pi)^{-4}f^{-5}$	Critical exceedance should be set at twice the value estimated by the Phillips spectrum, as this indicates unusual high frequency noise [Tucker, 1993]. The outcome of this test is dependent on whether a high frequency cut-off has been introduced. In processing of the PRIMaRE wave data, the high frequency cut-off has been chosen as $0.5Hz$ where $T = 2s$ and $\lambda = 6.25m$. This is close to the lowest theoretical operating frequency of the buoy (twice its diameter).
4	ratio, $H_{sig}/h_\sigma > 1.05$	Spikes in the time-series will increase the value of H_{sig} relative to h_σ. Thus, large spikes or flat spots in the data will cause a change to this ratio. A value of more than 1.05 is suggested [Tucker, 1993].
5	Number of data in the record that were flagged by direct time-series analysis	Identifies records where time-series analysis indicates errors
6	$P(\beta \neq 0)$,	where β is the gradient co-efficient calculated from a least squares analysis of η (see section ??). Identifies records where a significant linear trend is evident in the record of the time series.

Table 3. Quality control tests applied to wave spectra

In the final procedures, subsequent to quality control, the data will be passed to the real time data store. Subsequently, each month the data will be archived. At this time, a second quality control will run, examining the data for any unusual spikes. Furthermore, a final, single error flag will be assigned to each record based on the procedure in table 4. This will inform a report produced detailing the results of the process to be archived alongside the data.

Error	Action	Flag	Frequency			
			A	B	C	D
Out of range	Caution	10	0.01	0.01	0.01	0.01
Steepness	No action	20	0.17	0.21	0.16	0.18
Repetitions	Caution	30	0.03	0.03	0.03	0.03
Accelerations	Exclude	40	0.01	0.01	0.01	0.01
Heave res	Caution	1	0.02	0.01	0.02	0.02
Low freq noise	No action	2	0	0	0	0
High freq noise	No action	3	0.03	0.04	0.03	0.03
$H_{1/3}/H_\sigma$ ratio	No action	4	0	0.01	0	0
Trend test	No action	6	0	0	0	0
Out of H_{m0} range	Exclude	100	0	0	0	0
Out of T_z range	Exclude	200	0	0	0	0
Out of T_p range	Exclude	300	0	0	0	0
Out of Dir range	Exclude	400	0	0	0	0
$H_{buoy} \neq H_{pp}$	Caution	101	0.01	0.01	0.01	0.01
$T_{buoy} \neq T_{pp}$	Caution	201	0.00	0.01	0.02	0.01

Table 4. FaBTest defined protocol for dealing with errors identified in wave data

7.2 Report function

A report will be issued at the time of creation of each standard format archive file (Monthly). The number of files missing from that month is calculated as a percentage of the number of 30 minute periods during that month (48 per day). The maximum wave heights are rounded values of H_{m0} as calculated on-board the buoy from spectral analysis, and H_{max} as calculated on-board from direct time-series analysis. The frequency of occurrence of the different error flags is calculated as a percentage of the number of 30 minute periods during the month, and therefore will be a affected by the number of records returned during that month. For example, if 50% of records are missing, the maximum frequency of occurrence of any error is 50%. No analysis has yet been performed on the frequency of occurrence of different error flags. However, reports to date for wave buoy data immediately show the consistently high proportion of records are flagged for steep waves. Thus, this test is not used for buoy data.

8 Data Analysis and Research

This section details data analysis and research underway. The different applications described are designed to support testing at site and outputs will be applied to the direct benefit of developers within the suite of Matlab programs, as described in section 5.3

8.1 Waves

Waves at the site are classified by the extensive data available for the site. Key site statistics including the mean power and HT scatter diagram (fig. 18) have been computed and work is underway to automate these procedures for integration into the monthly archive process. In addition, these processes are being developed in order to develop best practice and improve the data supplied to site users.

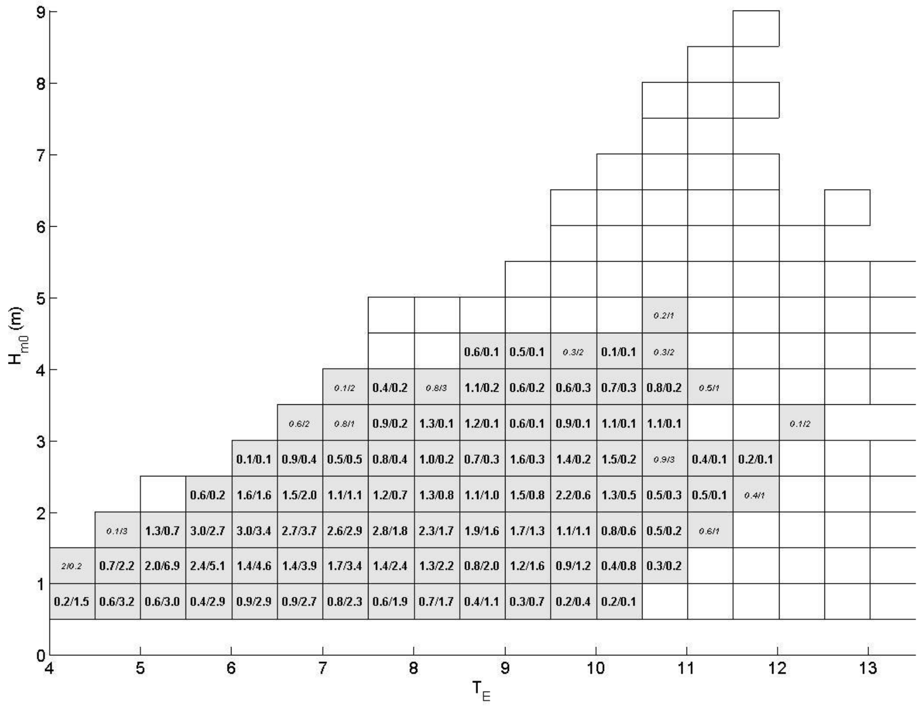


Figure 18, an H-T Scatter diagram showing those cells that are populated from both data sets. Numbers represent 'Proportion in winter/proportion in summer'. Values in italics show that on one of the data set, less than 0.5% of records occur in this cell, and the actual number of occurrences is shown.

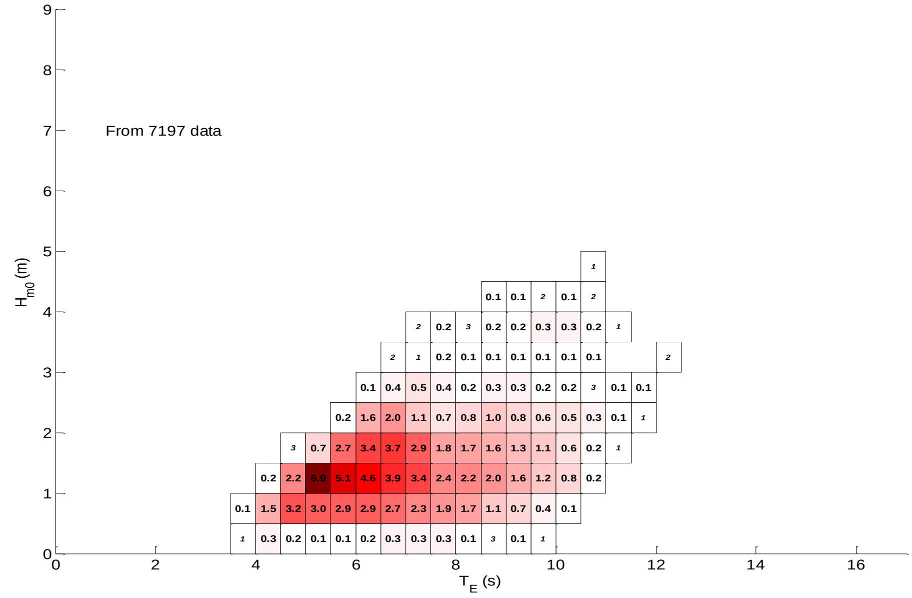
8.2 Variability in the scatter diagram

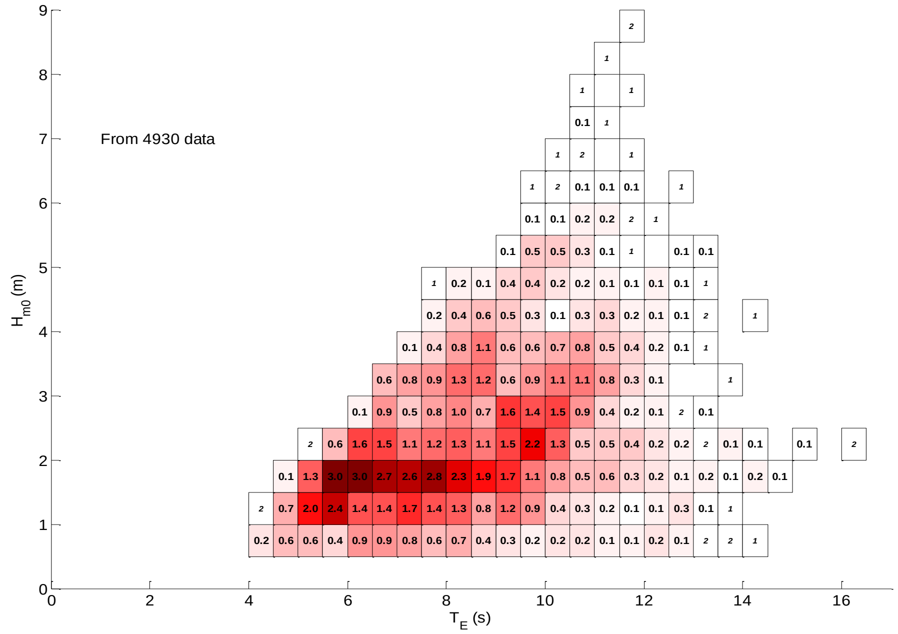
A key driver for testing at FaBTest is to derive data to predict performance at commercial sites. To do so, all data recorded (performance, mooring loads…) must be related in terms of the wave conditions experienced during testing and those expected at subsequent deployments. The FaBTest team have undertaken research designed to develop a methodology for interpreting test data for application to prospective deployment sites. The methodology quantifies the variability of the wave spectrum within each cell of the scatter diagram. In other words, does a wave height of 2m with 8s period look the same at each site?

The scatter diagram demonstrates differences in the wave conditions between two test data sets; in this instance, data from summer and data from winter from the same wave buoy (figs 19&20). Within co-existing cells, the frequency distribution of the sea states will be affected by the differences in the wave conditions, which cannot be fully resolved by the parameters H_{m0} and T_E.

For the four selected cells, there is discrepancy in the underlying spectra because of bi-modality in the spectra from the winter period (fig.21). A difference in the peak period is observed, which is not resolved by the energy period parameter. The expected failure of the T_E parameter to highlight this means that the low frequencies measured during either of the two distinct data sets cannot be considered representative of the low frequency measurements in the other data set. Importantly, where the most data are available from each data set, there is again a discrepancy at the peak mean period. This demonstrates that persistent low frequency differences can cause frequency discrepancies even where data are not restricted to a small number of co-existing records (fig. 21d).

Spectral differences between data sets in equivalent cells of the scatter diagram are expected to rely upon the number of records that are available in the cell from the two data sets. This was investigated through comparison of the proportion of records available, plotted against the magnitude of spectral differences (initially maxD was used) (fig. 22). This supports the initial hypothesis, with large differences only observed for cells representing fewer than 1% of both data sets. It should be noted that this comprises the minority of cells of the scatter diagram (approx. 35/105 populated cells). However, it should also be noted that very few of the cells with lower representation than this exhibit large differences. As a summary, the relationship between number of cells and differences is not explaining all of the variability in the data set.





Figures 19&20. The summer and winter scatter diagrams respectively. The difference in data availability is related to the gap in the data record during the winter data set. Numbers in italics represent actual number of records (where less than 0.5% of the data), and other values represent the proportion of the data set occurring in each cell.

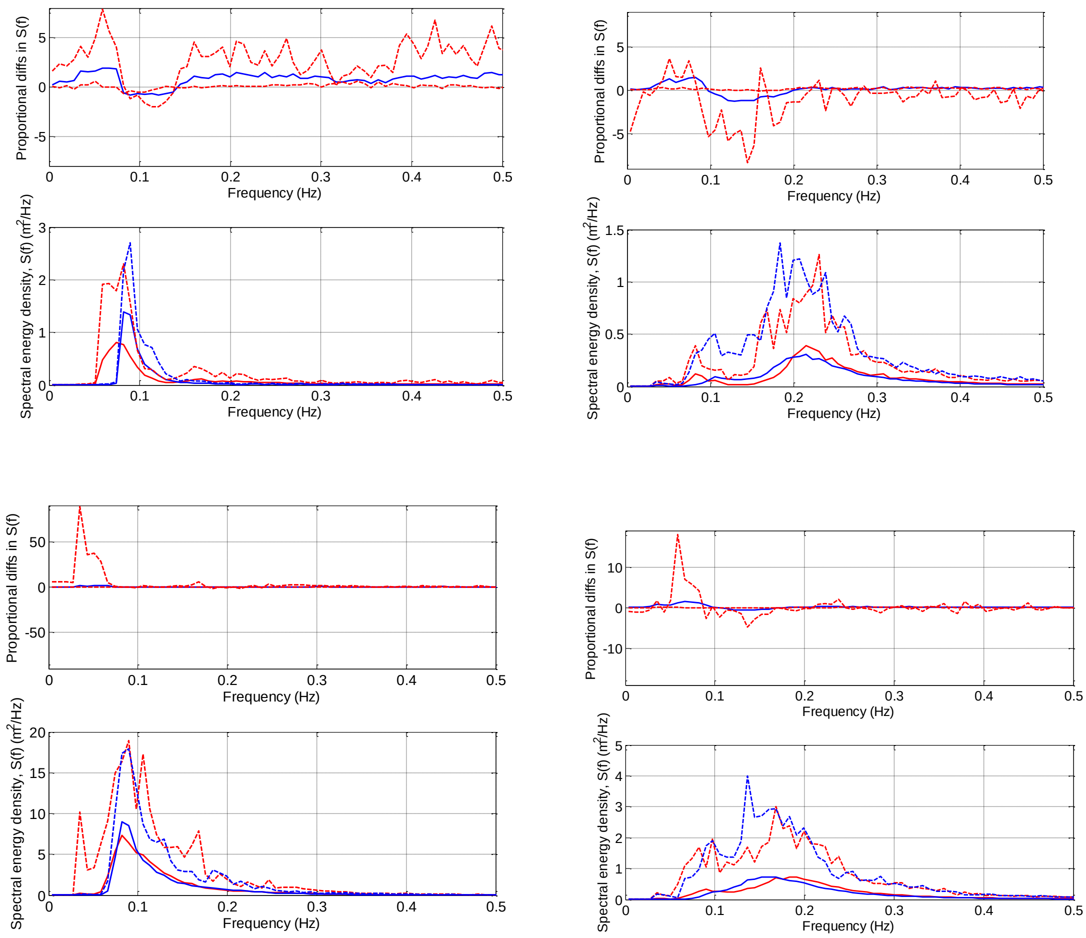


Figure 21. Spectra underlying cells of the scatter diagram for four chosen cells. Also shown are the corresponding proportional differences (%) in the mean and max spectra. Blue lines represent winter, red summer. Solid lines represent mean spectra, while dashed lines represent maximum and minimum spectral values at each frequency (produced using `VAR_specvar`)

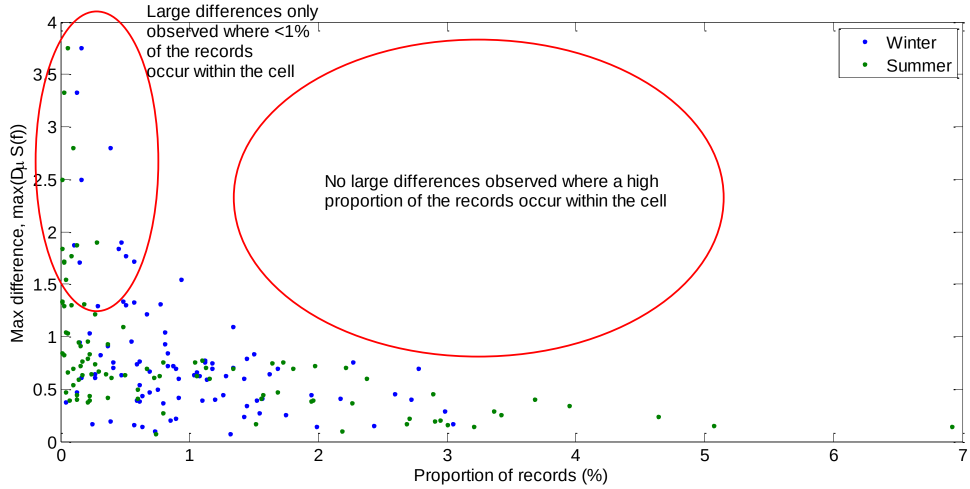


Figure 22. The maximum differences between spectra from corresponding cells of the scatter diagram, plotted against the proportion of records from each data set that contribute to that cell.

8.2.1 Relevance to device testing

The research has demonstrated how spectral variability can affect the interpretation of results and transferral of results to future deployments. Differences in the spectral values will translate to differences in power production and hydrodynamic loading between sites, even in conditions with the same combination of H_{m0} and T_E. A methodology has been developed to analyse the level of variability in the underlying wave conditions for each cell. Key recommendations include that analysis based on H/T cells with less than 1% of the measured data be used with caution as the variability of underlying spectra will be high.

8.3 Currents on site

In situ current monitoring has been used to relate site conditions with HW/LW in Falmouth and to validate modelling output available for the site. Tides at FaBTest are not equal in flood and ebb. And relating the timings of the tides to the freely available tidal forecasts shows uncertainty, important for marine operations.

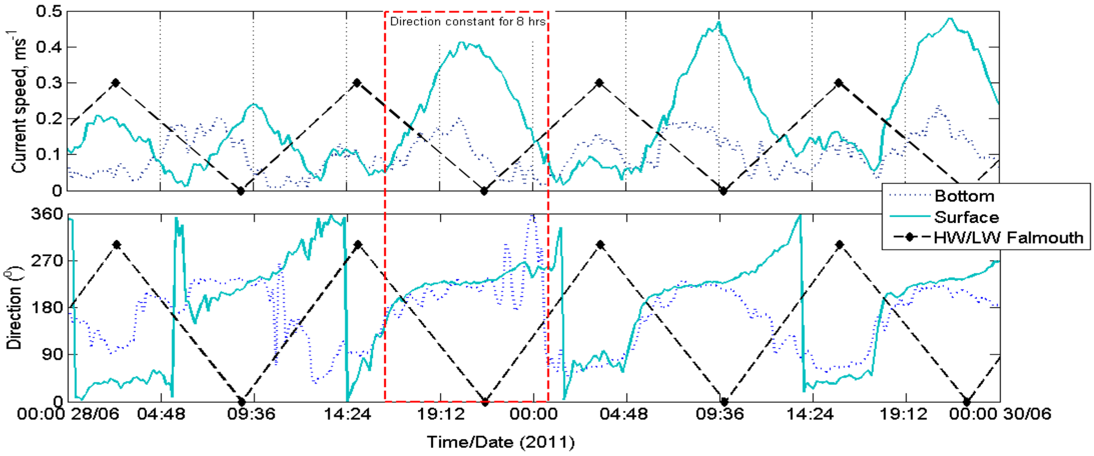


Figure 23. Tidal flow speed and direction for FaBTest site 28th June – 30th June 2011 showing a strong ebb tide causing current direction to remain constant over 8hrs, and reverse flow to be small in magnitude. Directions are shown as flowing to and as such a flood tide from SW to NE will have direction approx. 45°

In the measured data, inequalities in the tide were observed to cause unidirectional flow during periods up to 8 hours (Figure 23). The inequalities in the tide were not consistent, changing from tide to tide. There was no clear preference for inequalities during spring or neap, although the effects will be more pronounced during spring tides. On certain occasions, the very weak flood tide effectively extended slack water giving a period of 4 hours with flow speeds below 0.1m/s (fig. 24).

High water and low water Falmouth both correspond with peak flow at FaBTest. During the measurement period, HW/LW Falmouth occurred an average of 3hrs before slack tide on site. This time difference varied from 2Hrs to 4Hrs, with low water slack commonly exhibiting a longer delay.

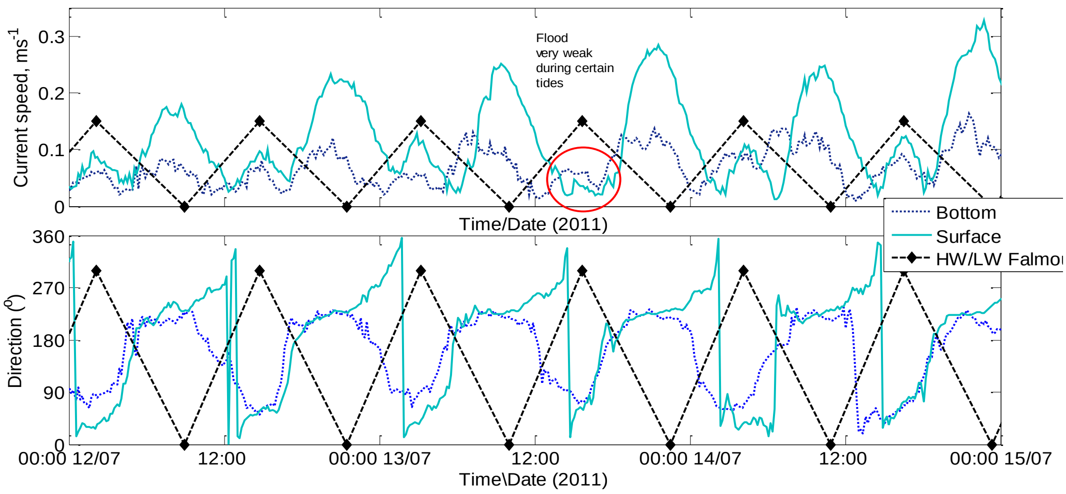


Figure 24. Flow speed and direction at the FaBTest site showing very weak flood tide which effectively causes an extended slack tide. Again, directions are shown as flowing to and as such a flood tide from SW to NE will have direction approx. 45°

These results refer to a 2 week time period, and may be affected by weather or other factors that may alter currents during the measurement period. As such, further analysis of future deployments would increase confidence that the results are representative of tidal conditions at site. Further research with these data would be required to begin to identify underlying causes of anomalies shown. This work stream would also benefit from analysis of model predictions for the site, which would have more relevance when planning operations.

8.4 Analysis principals for deriving peak mooring tension

Currently, the design of a mooring system for a typical oil and gas offshore structure is based on the prediction of the extreme mooring loads for a limited number of environmental conditions. During the design process, an inappropriate choice of environmental conditions could lead to an incorrect estimation of extreme mooring loads, which may result either in the loss of the mooring system or in a costly overdesign.

For mooring system analysis, DNV-OS-E301 recommends using several sea states with a return period of 100 years, with wave conditions given as a pair of significant wave height Hs and peak period T_p chosen along the 100-year envelope of the H_{m0}/T_p scatter diagram (e.g. fig. 18). A scatter diagram is obtained by classifying and then counting the number of occurrences of H_{m0} and T_p which have been measured or obtained by hindcast model.

An envelope line can then be drawn which shows the limitations between the sea states that did not occur, and the non-zero values. According to the representative standards, design calculations should be performed for several sea states along the upper part of this envelope.

Based on data gathered in Falmouth Bay, a methodology has been developed to determine which environmental conditions are inducing extreme mooring loads (Harnois 2014). It first assesses the joint probability distribution of wave conditions as a reference. Mooring loads are then assessed to identify extreme mooring loads, which have been analysed in respect to the corresponding wave conditions. Further, joint probability distributions of wave conditions that results in extreme mooring loads are determined.

8.4.1 Assessment of the site wave conditions

The percentage of occurrence of each Hs/Tp pairs is calculated. The contour plot is drawn (Figure 25) using an appropriate contour scale, based on the maximum values in the percentage of occurrence matrix. A maximum of six curves could be plotted for clarity reasons, each curve corresponding to a range of percentage of occurrences. The last range can be corresponding to all values above the last range. For example, a point on this plot between a 3% and 6% curve means that between 3% and 6% of the measured sea states were occurring in the range of Hs and Tp values delimited by the grid. Statistical wave data are then interpolated to the same time step as the mooring load time series.

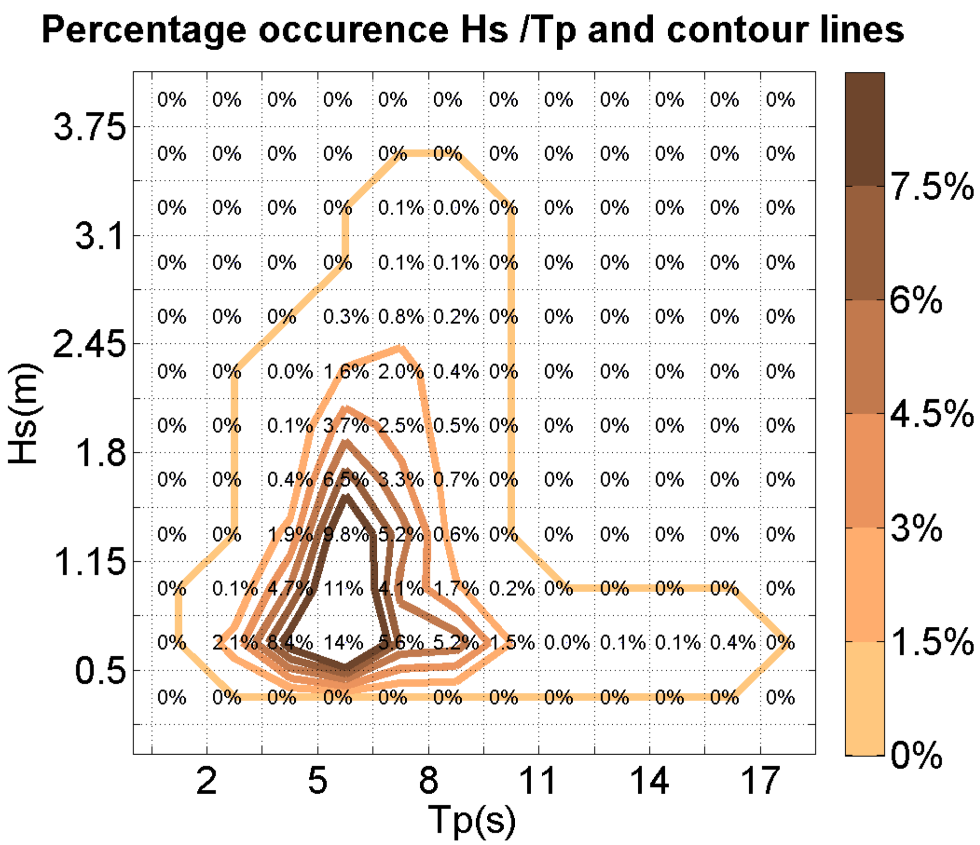


Figure 25. Example of joint probability distribution of Hs/Tp (a) and its contour plot at SWMTF

In this example, the measured wave climates can be classified in 39 sea states, classified in bins of 0.325m H_{sbin} and 1.5s T_{pbin}, with Hs0 equal to 0.5m and Tp0 equal to 2s. The contour plot of the joint probability distribution of Hs and T_p (Figure 25) indicates that most of the wave climates occurred for Hs below 2.1m and T_p below 9.5s, with a maximum Hs over 3m.

8.4.2 Selection of extreme mooring loads

Extreme mooring loads are selected in the whole dataset of mooring loads. An extreme mooring load is defined as a mooring load with an amplitude which is significantly higher than the other mooring loads occurring at similar time.

A Peak Tension Threshold K is introduced to isolate extreme mooring loads. K is compared to the standard score of a dataset of several minutes of mooring loads. The standard score (eq 1) of a dataset gives the difference between the maximum and the mean in units of the standard deviation and allowed the comparison of a) of the dynamic part of the mooring load: the amplitude of the maximum mooring load minus the mean mooring load which is the mooring line pretension, or static load, and b) of the dispersion, or spreading, of the mooring loads at this time.

$$S_{max}(x) = \frac{\max(x) - \bar{x}}{\sigma_x} \tag{1}$$

With the standard score of the maximum,   the mean of x and the standard deviation of x. Datasets with a standard score over K indicate that a peak event occurred during this dataset.

A Minimum Tension Threshold τ is introduced and datasets with a maximum mooring load below this value are not considered as extreme. The Minimum Tension Threshold τ is aiming to remove events in a calm sea state which are not relevant for this study, such as collisions or ship wake. For example, in Figure 26, the standard score of the maximum was higher than K and the maximum mooring load was higher than τ. An extreme mooring load was then detected. In Figure 27, the standard score of the maximum was higher than K but the maximum mooring load was lower than τ. No extreme mooring load was detected in this dataset.

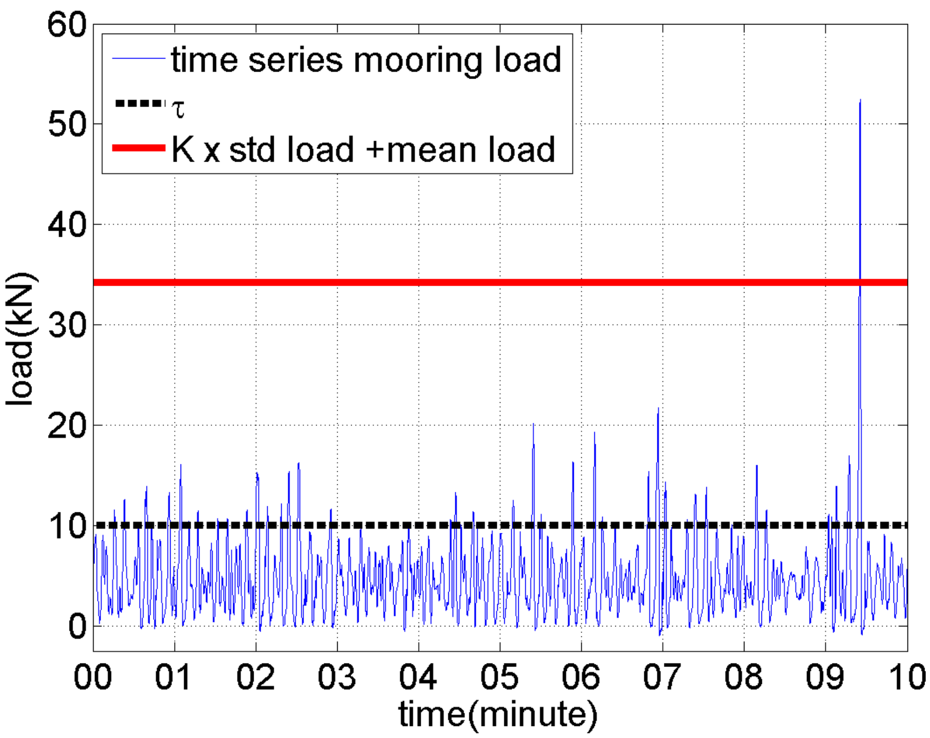


Figure 26 Example of a 10 minute dataset showing a detected extreme mooring load

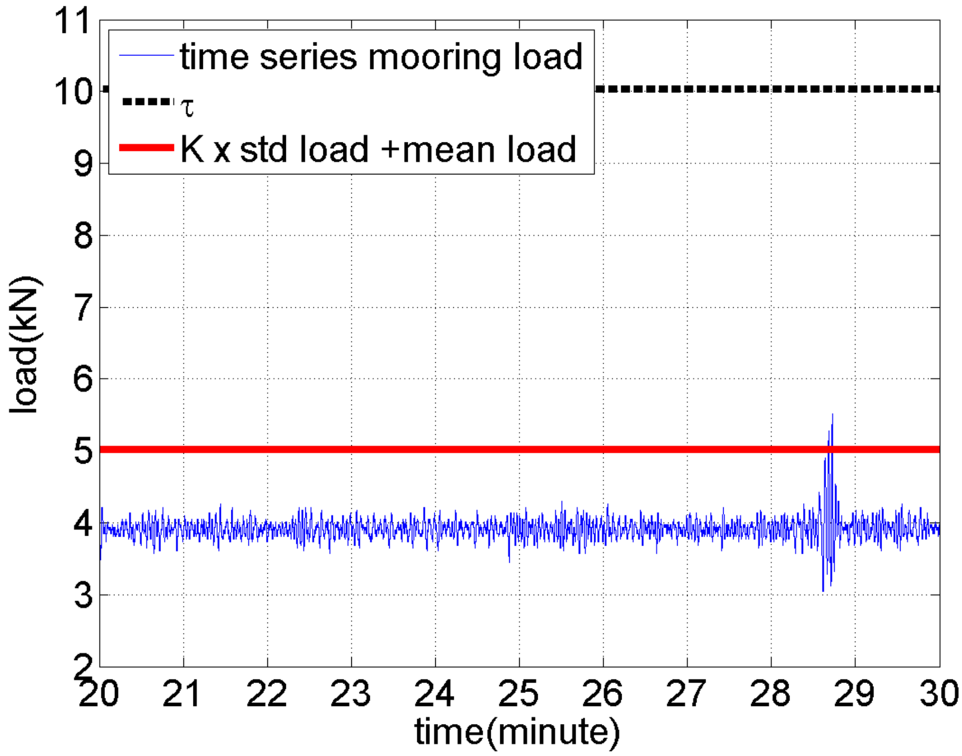


Figure 27 Example of a 10 minute dataset showing a large mooring load compared to the adjacent mooring loads, but with not sufficient overall amplitude to be considered as an extreme mooring load

If τ is set to 0kN and K to 0, this means that all datasets are identified as containing extreme mooring loads. Fewer values are selected when τ and K are higher. A mooring system with a high number of mooring lines, or in a quieter environment will be less likely to observe extreme mooring loads at similar Peak Tension Threshold K and Minimum Tension Threshold τ. K and τ are chosen depending of the facility parameters such as number of mooring lines, environment, mooring compliance, and of the severity of selected extreme mooring loads. The same values for K and τ are applied to all mooring lines.

For each mooring load dataset, the maximum value and the standard score were calculated. If the maximum value and the standard score were higher than τ and K respectively (fig. 27), then an extreme mooring load was detected. The interpolated wave data Hspeak/Tppeak corresponding to a dataset containing an extreme mooring load were recorded.

8.4.3 Extreme mooring loads and their corresponding environmental conditions

The joint probability distribution of Hs_{peak}/Tp_{peak}, the wave conditions which were identified during an extreme mooring load, is calculated and a contour plot is drawn to summarise the results. The envelope of the H_s/T_p joint probability distributions is added to this plot.

The joint probability distribution of Hspeak and Tppeak (fig. 28) indicates that in this example extreme mooring loads occurred most commonly in the range $1.5m<H_s<3.3m$ and $4s<T_p< 9s$ on line 3. It also shows that the 30 mooring loads with the highest amplitude occurred in a similar range of values.

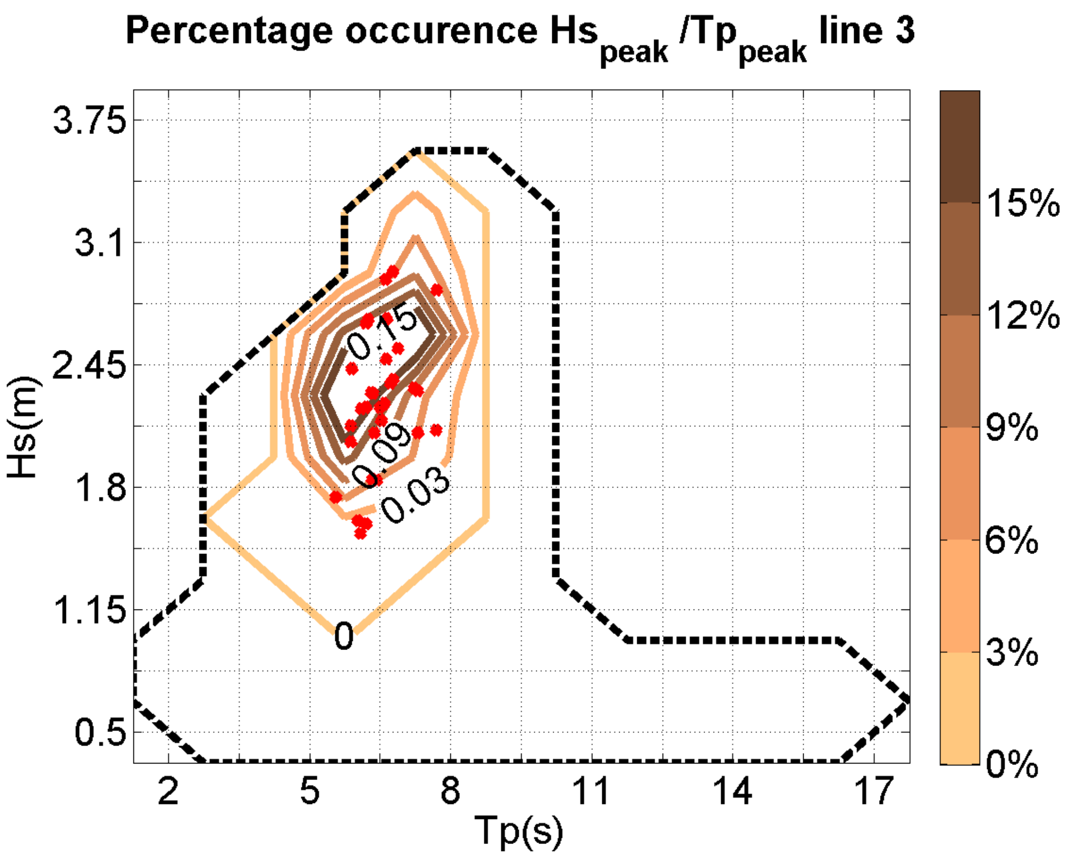


Figure 28. Joint probability distribution of Hspeak/Tppeak on mooring line 3 at SWMTF (coloured solid lines), envelope of the joint probability distribution of Hs/Tp at SWMTF (black dashed line), and 30 mooring loads with the highest amplitude(red dots)

For certain values of H_{m0}/T_p, a small likelihood of the wave conditions associated with a likelihood of Hspeak/Tppeak (probability of extreme mooring loads) means that the wave conditions, although not common, are likely to induce extreme mooring loads. As such, this methodology offers a more refined prediction of the extreme mooring loads than current standards and common practice.

This same methodology is valid for other environmental parameters such as the current velocity and the water depth. This forms part of ongoing research and offers valuable analysis for site users planning deployments and when reviewing data and analysing system performance.

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Appendix A - Spectral Analysis

Wave data sampling is set to take place over 1024 seconds (17 minutes 4 secs), at a frequency of 2Hz, giving 2048 data points for each wave record. For the wave buoy data, this is sea surface position in heave, easterly, and northerly directions. For ADCP data, this is orbital velocities in the same directions.

Spectral analysis decomposes the time-series of surface elevation, $\eta(t)$, into N component regular waves of different frequencies, represented by a Fourier series as,

$$\eta(t) = \sum_{i=1}^{N} [a_i \cos(2\pi f_i t) + b_i \sin(2\pi f_i t)] \tag{A1}$$

The amplitudes a_i and b_i are calculated from the time-series for each Fourier harmonic using a periodogram method, and the spectral variance density is calculated as,

$$\hat{S}_j(f)\Delta f_j = \tfrac{1}{2}\sum_{i=1}^{k} (\hat{a}_i^2 + \hat{b}_i^2) \tag{A2}$$

for $j = \{1,2...N\}$, where hats denote estimated quantities. Data are averaged over 8 frequencies ($k = 8$), giving a variance density spectrum for 128 individual frequency bands, between 0 and the Nyquist frequency (1Hz), with resolution, $\Delta f = 0.0078$ Hz.

Spectral moments are calculated from the averaged, spectrum as,

$$\hat{m}_n = \int_{f_1}^{f_2} f^n \hat{S}(f)df \tag{A3}$$

where n represents the order of the spectral moment. Spectral moments are then used to calculate the significant wave height,

$$H_{m0} = 4\sqrt{m_0} \tag{A4}$$

and mean wave period,

$$T_E = {m_{-1}}/{m_0} \tag{A5}$$

T_P is calculated as the period corresponding to the maximum spectral energy density in the variance spectrum.

Directional analysis

The directional spectrum can be represented as the product of the spectral variance density, $S(f)$, and a directional distribution, $D(\theta, f)$,

$$S(f,\theta) = S(f)D(\theta, f) \tag{A6}$$

for the directional distribution,

$$\int_{-\pi}^{\pi} D(\theta, f) d\theta = 1 \qquad \text{(A7)}$$

It follows that the directional distribution can be considered as periodic in direction, θ, and can be described in terms of angular harmonics,

$$D(\theta, f) = \frac{1}{\pi}\left\{\frac{1}{2} + \sum_{n=1}^{\infty}(A_n(f) cos\ n\theta + B_n(f) sin\ n\theta)\right\} \qquad \text{(A8)}$$

Here, the directional distribution is assumed to be of the form,

$$D(\theta, f) = F(s) cos^{2s}\tfrac{1}{2}(\theta - \theta_m) \qquad \text{(A9)}$$

Where θ_m is the direction at each frequency, s is the spreading, also a function of frequency, and $F(s)$ is a factor such that equation (Df=1) is satisfied. θ_m values are estimated from the first angular harmonics,

$$tan\theta_1 = {}^{b_1}/_{a_1} \qquad \text{(A10)}$$

Tucker and Pitt (2001) highlight a 180° ambiguity in the estimation of θ_1, which is resolved from the sign of the values.

The mean direction, m_{dir}, is calculated as,

$$m_{dir} = \tan^{-1}\left(\frac{\int S(f)\cos(\theta_m(f))df}{\int S(f)\sin(\theta_m(f))df}\right) \qquad \text{(A11)}$$

giving a weighted mean of wave direction across all frequencies.

Appendix B - File naming structure

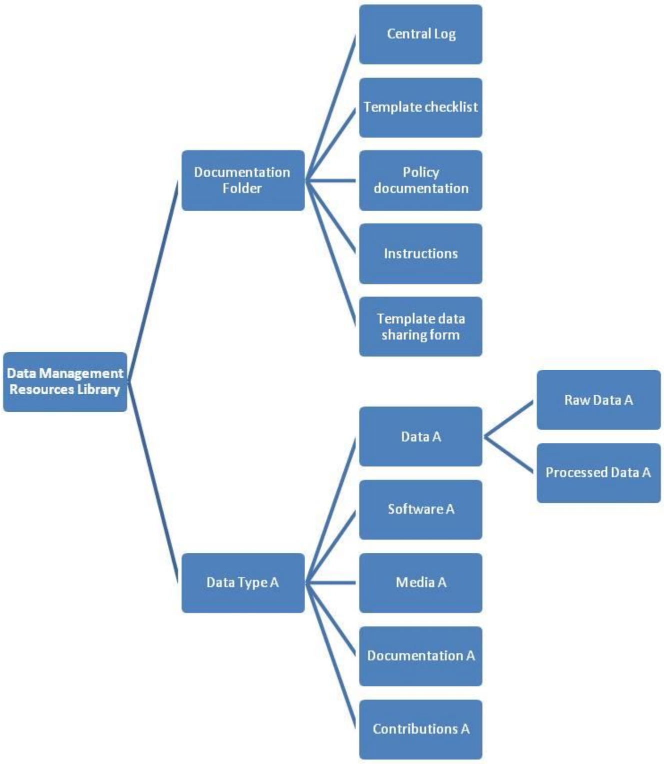

Figure B1: DMRL Structure

Data managers will store their data in one folder per data type on the P drive. All information and data associated with the data source will be stored in the folder. This should allow a user to require no extra information when downloading data in a usable format. Within each folder will be 5 sub-folders entitled:

- Data
- Software
- Media
- Documentation
- Contributions

This structure is fixed, although subfolders can be used. File names should include a structure of a) data type (e.g. WB for wave buoy), b) date (format YYYYMMDD) and, c) any relevant specification. Where this is not possible (e.g. for raw files generated by the sensor), a detailed description of file names should be kept, and possibly a log containing the date of generation. File naming should be checked with the Data Supervisor prior to implementation, and will be monitored at review.

The DMLR will also contain a central documentation folder comprised of:

- A central log. This will be in the form of a spreadsheet with the fields:

1. Instrument name (e.g. model name of sensor)

2. Data manager
3. Data ownership and reference to the legal obligations.
4. Users with data access rights
5. Classification(s) of data
6. Predicted rate of data accumulation (see setup procedure, section 7)
7. Predicted date of end of project
9. Actions relating to this dataset (e.g. review, additions, deletions etc…)

- Template checklist for sharing document
- Template data sharing form
- Instructions on using the data centre
- Policy documentation including funders' and institutional policies and model data management plans for research proposals.

i. Data

The data folder will have two subfolders:

- Raw data - raw files collected from the equipment. A readme file is permitted but no other files will be present in this folder
- Processed data – The processed data will be used to receive any data that has been subject to automated processing routines, or through manual processing. It is important to document the process in a readme file. Duplicate data should be avoided in this folder.

ii. Software

The software folder will include any software that is required (or useful) for the analysis of the raw data. This will include the program required to derive the data in the processed data folder from the raw data.

iii. Media

The media folder includes all pictures and videos of the equipment or other relevant pictures and videos. Presentations that refer to the specific data in the data source folder should be included. Publications based on the dataset should be uploaded to the publications library and assigned to the relevant dataset(s).

iv. Documentation

The documentation folder includes all documentation for the equipment, and specifications. Documentation must be stored with the data to ensure that it can be used effectively, and re-used in the future. Documentation should be in line with the metadata fields required for the institutional repository
It must include the University's legal agreement with regards data accumulated during the project.
Where appropriate, it should also include the following:

- Text documents explaining how data are created, their content, structure, and details of file naming protocol as well as definitions of specialist terms and acronyms used.

- Name, model and description of instrument
- Clarification of dates (format YYYYMMDD) and times, including the time-zone
- Calibration certificates.
- Any documentation relevant to data creation methodology (e.g. user manuals).
- Position of instrument
- Sampling frequency
- Input to test (lab equipment)
- Other details of instrument setup (perhaps a setup file)
- Maintenance performed on instrument (may cause bad data)
- Instructions for any software and advice on further processing of the data
- Details of any processing the instrument has already performed (reference the manual or other documentation)
- Any other information that may be relevant to future processing/analysis
- For processed data, the full details of the processing should be stored, including quality control processes.

v. Contributions

The contribution folder is designed to allow all users with authorisation to view a dataset, to enhance the dataset. This folder will be open to all users to upload any files to be included in the filing system. This would include processed data, presentations, media, papers and any scripts that have been written as well as any data in a further processed form that may be useful. It is the responsibility of the data manager to maintain this folder, moving relevant contributions to the media folder and deleting old or obsolete contributions. Management decisions for files in this folder are taken by the data manager, and may be deleted as they decide. For users, it should not be considered as secure storage (copies should be retained), unless transferred to another folder by the data manager.