SUPPORT DOCUMENT FOR THE REDAPT TIDAL SITE ENVIRONMENTAL DATA ARCHIVE

AN INTRODUCTION TO THE REDAPT TIDAL PROJECT ENVIRONMENTAL DATA SET

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v2.0

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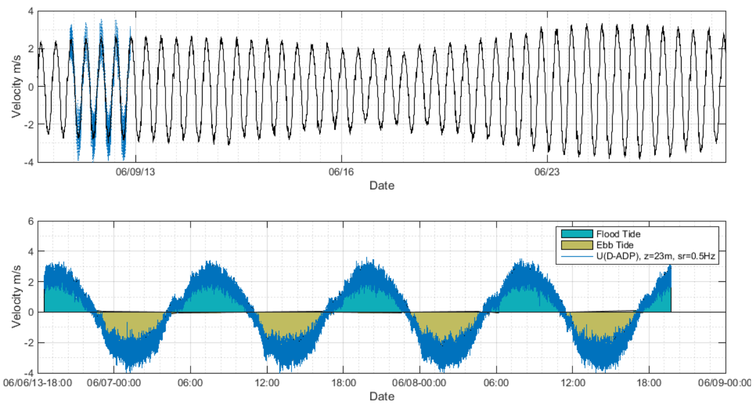


Contents

1 Project Background

This document provides brief background information on the main outputs of the University of Edinburgh's field measurement campaign conducted as part of the Energy Technology Institutes's ReDAPT project. It has been produced to specifically assist data users understand the data that has been made available to the public as part of this work. For more detailed information on the ReDAPT tidal flow characterisation works please see:

PDF LINK: ReDAPT Technical Report: MD3.8 Tidal Site Characterisation
(URL: `http://redapt.eng.ed.ac.uk/index.php?p=library_redapt_reports`)

1.1 ReDAPT within the ETI Marine Programme

The Reliable Data Acquisition Platform for Tidal energy (ReDAPT) project was commissioned and co-funded by the Energy Technologies Institute (ETI) under their Marine Programme whose central objective is to accelerate the development and deployment of commercially viable marine energy technologies that will:

- Make a material contribution to the future UK energy system
- Deliver significant greenhouse gas emissions reductions
- Contribute to the delivery of long-term energy security in the UK

Specifically, their Marine Programme seeks to contribute to the delivery of marine energy cost reduction and performance improvements in line with the ETI Marine Energy Roadmap.

ETI Library URL: `www.eti.co.uk/library`
ETI Marine URL: `www.eti.co.uk/programmes/marine`

1.2 The ReDAPT Project

ReDAPT was led by Alstom and included the University of Edinburgh (UoE), DNV-GL Renewable Advisory, EDF Energy, E.ON, Tidal Generation Ltd., Plymouth Marine Laboratory and the European Marine Energy Centre (EMEC). The project centred around a commercial scale (1MW) tidal turbine developed by Alstom deployed at EMECs Tidal Test Site with the aim of producing a comprehensive suite of data on turbine operation, the flow field and the interaction between the two. ReDAPT was a five year programme intended to provide information to the Tidal Industry to facilitate rapid growth. Specific goals included:

- Acceleration of development of tidal energy industry
- Successful deployment and operational testing of a 1MW system at EMEC, delivering substantial learning to the acceleration of commercial product roll-out
- Data, insights and lessons learned are recognised as key reference materials and are used by the industry, e.g. Device performance
- Environmental monitoring and resource assessment
- Industry certification standards and protocols informed by ReDAPT outcomes
- Increased confidence in tidal turbine technologies
- Validation and industry acceptance of tidal flow/machine models

2 The ReDAPT "Modelling" Work Package

Data was extensively acquired to meet the demands of the numerical modelling teams. Specific to the "Modelling" (MD) work package, validation of engineering tools formed a core project outcome through comparison of predicted to experienced loads *under measured environmental conditions.*

The data that enabled the validation of these engineering tools whilst also forming the basis of an in-depth site characterisation study has now been uploaded to the UK Energy Research Centre's Energy Data Centre (UKERC-EDC).

The data is available as a "frozen" repository and a "living" in-use and updated set. These can be accessed from:

1. Permanent archive of data from snapshot at project end:
`http://data.ukedc.rl.ac.uk/simplebrowse/edc/renewables/marine/`
2. Up-to-date data and in-use by researchers:
`http://redapt.eng.ed.ac.uk`

2.1 Modelling Work Package Outputs

For further reading related to the outputs of the ReDAPT Modelling Work Package please see:

- Cutting-edge numerical simulation of the Alstom 1MW tidal turbine in turbulent flows [1, 2]
- Construction and validation of a hydrodynamic model of the wider Fall of Warness, Orkney site [3, 4]
- The validation through comparison to field and machine data of DNVGL-RA Tidal Bladed software [5, 6]
- TEC mounted velocimetry and development of high resolution instrumentation systems [7–10]
- TEC site characterisation report [11]
- TEC power curve production [12]

2.2 The University of Edinburgh's Field Measurement Campaigns

The objective of the University of Edinburgh's work package was to design and conduct a data acquisition campaign to increase understanding of the flow conditions in the near-field of a tidal stream turbine and to increase confidence in flow measurement and analysis methods. Activities centred on near-field flow characterisation where near-field is defined herein as up to 10 rotor diameters range from the turbine. Three primary activities were originally identified with a fourth added during project review:

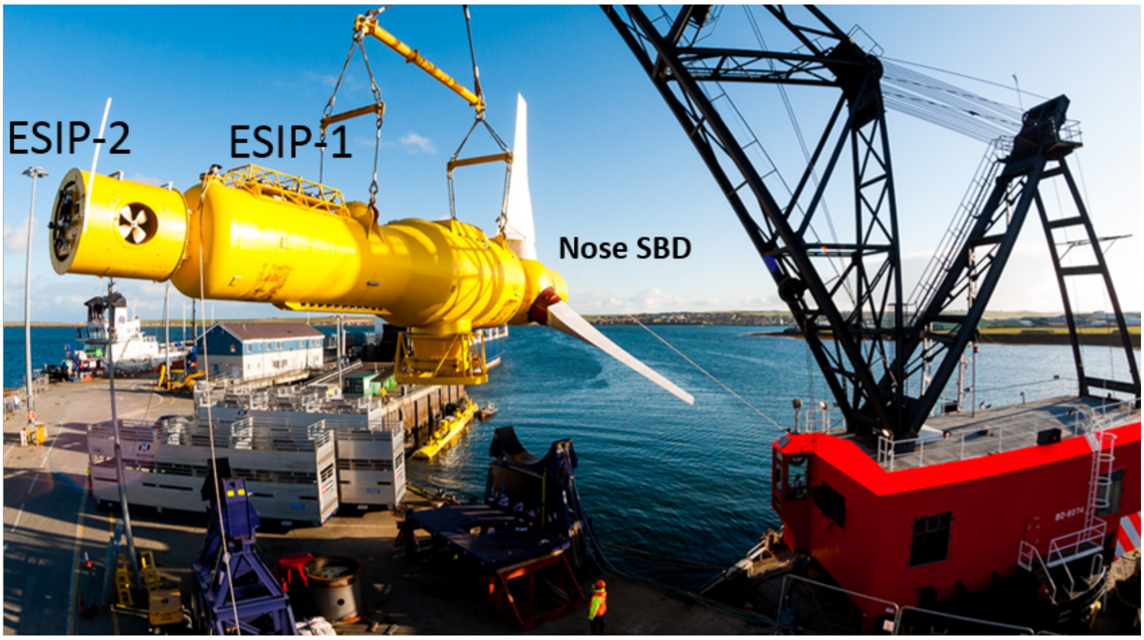


Figure 1: Photograph of DEEPGEN IV being lifted by crane barge prior to deployment. Locations of the UoE instrument platforms, ESIP-1, ESIP-2 and the nose SBD identified.

- Site mean-flow and turbulence characterisation
- Acquisition, processing and dissemination of data for the validation of the ReDAPT numerical models
- Recommendations for monitoring parameters and equipment type
- **Additional: Provision of data in a format suitable for archival and access by the Industry**

3 The Field Data

Tidal sites are energetic and complex systems featuring turbulent flows, surface water waves, varying bathymetry and never-constant mean-flow conditions - to name a few aspects of their character. Tidal site characterisation in the context of this work has been driven by the immediate requirements of tidal turbine developers i.e., providing information on the flow impressing upon a commercial scale tidal turbine. The specification for this information is in turn driven by the data input requirements of the engineering tools used by device designers and operators, namely simulations using Computational Fluid Dynamics and other modelling techniques. **Other site characterisation works would likely focus on alternative aspects of the flow and subsequently target alternative data.**

Due to the volume of data collected, the resource required to sustain the duration of data campaigns and moreover the multiple variants of data sets returned by both established and prototype instruments operating across a wide variety of configurations much further analysis could be carried out.

Data analysis is ongoing at the University of Edinburgh and we welcome collaborations, joint-publications and further discussions.

Please see the report below for further information.
PDF LINK: ReDAPT Technical Report: MD3.8 Tidal Site Characterisation
(URL: http://redapt.eng.ed.ac.uk/index.php?p=library_redapt_reports)

4 The Data Archive

Environmental data has been uploaded to the UK Energy Research Centre's Energy Data Centre (UKERC-EDC) where it will be permanently archived. It is available in both MATLAB v7.3 format and has also been converted to netcdf format. The data comprises data from the following instruments acquired between June 2011 and October 2014:

- Seabed mounted D-ADP (*ADCP*)
- Turbine mounted SB-ADP *(SBD)* data in multiple orientations where the instrumentation was in a stable configuration.
- Turbine mounted D-ADP *(AWAC)* data where instrumentation configuration is stable.
- Turbine mounted SB-ADP Long Range (CONT - Nortek Continental)

4.1 End-User Agreement and Disclaimer

Use of the data is subject to the following End-User Agreement and Disclaimer:

> End-User Agreement and Disclaimer related to use of Data
>
> You, (the End-User), are about to access certain data, (the Data) which has been gathered during a research project, (entitled ReDAPT), and by continuing you acknowledge that the Data is presented here 'as is', without any commitment that it is complete, accurate of suitable for any specific use or purpose to which you may wish to put the same.
>
> Specifically, no warranty or other assurance is given or should be implied that use of the Data will generate any particular end or result, or that your use of the Data will be uninterrupted or error-free, and all other conditions, warranties or other terms which might have been implied, whether by statute, common law or otherwise, are hereby excluded, including the implied conditions, warranties or other terms as to satisfactory quality, fitness for purpose or the use of reasonable skill and care.

We recommend and welcome collaborating on analysis and publications due to the complex nature of the dataset. The minimum requirement for use of the data is an acknowledgement of the data source using the latest references that are listed at the point of data download.

Table 1 provides an overview of the instruments that provided data in the archive along with the configurations used.

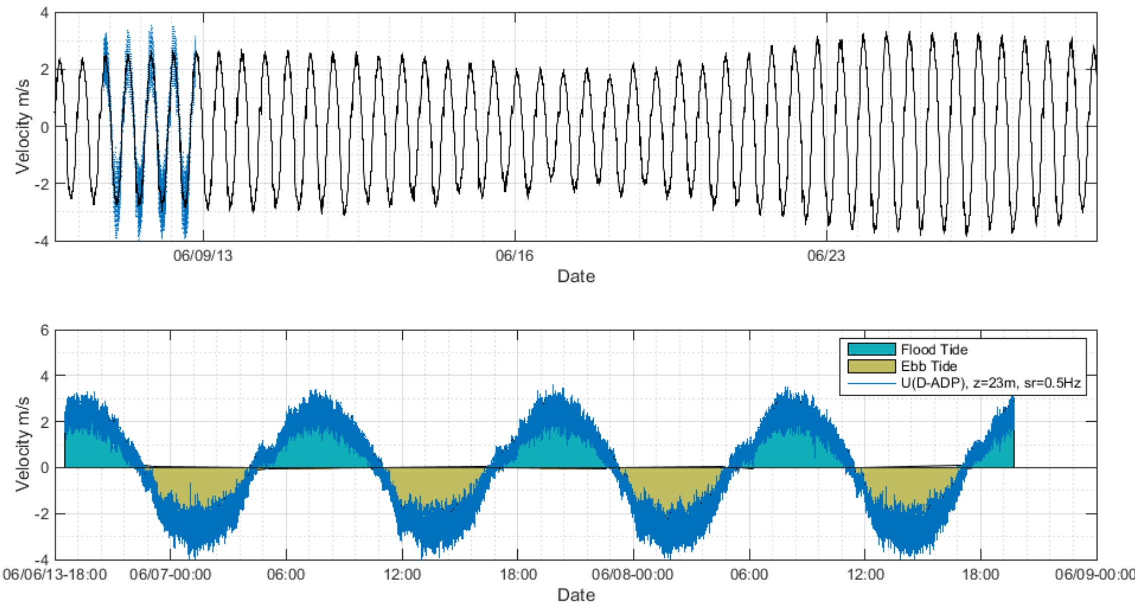


Figure 2: Example of archived data. Tidal cycles (June 2013) from the Fall of Warness, Orkney showing defined Flood and Ebb tidal streamwise velocities. Two data types shown: averaged to 5 minutes (top) and underlying high frequency raw data at 0.5Hz (overlaid and bottom).

System state data is also provided to help end-users filter data. Indicative tidal states of flood and ebb are provided as is the turbine orientation to north along with a signal defining periods of turbine generation and a depth-averaged reference velocity produced from upstream ADCP data where available. This is shown in Table 2.

Table 3 provides the archive data sources (instruments) unique names, dates of coverage and installation location.

4.2 Matlab Data Fields

4.2.1 List of fields in each structure, typical dimensions and class

Workspace

Name	Size	Value	Bytes	Class
Amp1	29700x49	29700x49 ...	5821200	single
Amp2	29700x49	29700x49 ...	5821200	single
Amp3	29700x49	29700x49 ...	5821200	single
Amp4	29700x49	29700x49 ...	5821200	single
B1	29700x49	29700x49 ...	5821200	single
B2	29700x49	29700x49 ...	5821200	single
B3	29700x49	29700x49 ...	5821200	single
B4	29700x49	29700x49 ...	5821200	single
CF	29700x20	29700x20 ...	4752000	double
Heading	29700x1	29700x1 s...	118800	single
Info	1x1	1x1 struct	3440	struct
Pitch	29700x1	29700x1 s...	118800	single
Pressure	29700x1	29700x1 s...	118800	single
Roll	29700x1	29700x1 s...	118800	single
Timestamp	29700x1	29700x1 d...	237600	double
X	29700x49	29700x49 ...	5821200	single
Y	29700x49	29700x49 ...	5821200	single
Z	29700x49	29700x49 ...	5821200	single

Matlab file structure. ADCP instrument in RAW format.

Workspace

Name	Size	Value	Bytes	Class
Amp1	29700x49	29700x49 ...	5821200	single
Amp2	29700x49	29700x49 ...	5821200	single
Amp3	29700x49	29700x49 ...	5821200	single
Amp4	29700x49	29700x49 ...	5821200	single
B1	29700x49	29700x49 ...	5821200	single
B2	29700x49	29700x49 ...	5821200	single
B3	29700x49	29700x49 ...	5821200	single
B4	29700x49	29700x49 ...	5821200	single
CF	29700x20	29700x20 ...	4752000	double
EAST	29700x49	29700x49 ...	5821200	single
Heading	29700x1	29700x1 s...	118800	single
Info	1x1	1x1 struct	3440	struct
NORTH	29700x49	29700x49 ...	5821200	single
Pitch	29700x1	29700x1 s...	118800	single
Pressure	29700x1	29700x1 s...	118800	single
Roll	29700x1	29700x1 s...	118800	single
Timestamp	29700x1	29700x1 d...	237600	double
UP	29700x49	29700x49 ...	5821200	single
X	29700x49	29700x49 ...	5821200	single
Y	29700x49	29700x49 ...	5821200	single
Z	29700x49	29700x49 ...	5821200	single

Matlab file structure. ADCP instrument in QC format. Quality Control has been applied. Time is in GMT. East, North and Up velocity fields have been created using compass information and any external orientation references.

DATA_DA

P... V... V...

No Variable Selected

SELECTION

PLOTS

OPTIONS

1x1 struct with 21 fields

Field	Value	Size	Class
Amp1	99x49 single	99x49	single
Amp2	99x49 single	99x49	single
Amp3	99x49 single	99x49	single
Amp4	99x49 single	99x49	single
B1	99x49 single	99x49	single
B2	99x49 single	99x49	single
B3	99x49 single	99x49	single
B4	99x49 single	99x49	single
CF	99x20 double	99x20	double
EAST	99x49 single	99x49	single
Heading	99x1 single	99x1	single
Info	1x1 struct	1x1	struct
NORTH	99x49 single	99x49	single
Pitch	99x1 single	99x1	single
Pressure	99x1 single	99x1	single
Roll	99x1 single	99x1	single
Timestamp	99x1 double	99x1	double
UP	99x49 single	99x49	single
X	99x49 single	99x49	single
Y	99x49 single	99x49	single
Z	99x49 single	99x49	single

Matlab file structure. ADCP instrument in DA (Data Analysed) format. Data is averaged to five minute ensembles.

4.2.2 Description of fields - ADCP

Data Fields	Sub Fields	Dimensions	Number Format	Description	Units
Timestamp	NO	1D	double	Timestamp (Matlab format)	days
B1	NO	2D	single	Velocity Profile from Beam 1	m/s
B2	NO	2D	single	Velocity Profile from Beam 2	m/s
B3	NO	2D	single	Velocity Profile from Beam 3	m/s
B4	NO	2D	single	Velocity Profile from Beam 4	m/s
X	NO	2D	single	Velocity Profile in instrument X coordinates	m/s
Y	NO	2D	single	Velocity Profile in instrument Y coordinates	m/s
Z	NO	2D	single	Velocity Profile in instrument Z coordinates	m/s
Amp1	NO	2D	single	Amplitude Return Profile from Beam 1	counts
Amp2	NO	2D	single	Amplitude Return Profile from Beam 2	counts
Amp3	NO	2D	single	Amplitude Return Profile from Beam 3	counts
Amp4	NO	2D	single	Amplitude Return Profile from Beam 4	counts
Heading	NO	1D	single	Instrument Heading	degrees
Pitch	NO	1D	single	Instrument Pitch	degrees
Roll	NO	1D	single	Instrument Roll	degrees
Pressure	NO	1D	single	Instrument Depth from Pressure Gauge	m
EAST	NO	2D	single	Velocity Profile in Earth coordinates (EAST)	m/s
NORTH	NO	2D	single	Velocity Profile in Earth coordinates (NORTH)	m/s
UP	NO	2D	single	Velocity Profile in Earth coordinates (UP)	m/s
CF	YES	2D	double	Instrument Configuration Tracking fields	Multiple (see CF_VALUE_n)
CF	VALUE 1	1D		N/A	
CF	VALUE 2	1D		N/A	
CF	VALUE 3	1D		MatlabTimestamp	days
CF	VALUE 4	1D		ErrorCode	see RDI ADCP manual
CF	VALUE 5	1D		SoundSpeed	m/s
CF	VALUE 6	1D		Heading	degrees
CF	VALUE 7	1D		Pitch	degrees
CF	VALUE 8	1D		Roll	degrees
CF	VALUE 9	1D		Instrument Depth from Pressure Gauge	m
CF	VALUE 10	1D		Temperature	degrees C
CF	VALUE 11	1D		Number of Beams	
CF	VALUE 12	1D		Number of Bins	
CF	VALUE 13	1D		Sample Rate	Hz
CF	VALUE 14	1D		Location of first measurement Bin	m
CF	VALUE 15	1D		Location	UTM Zone 30 N, metres East
CF	VALUE 16	1D		Location	UTM Zone 30 N, metres North
CF	VALUE 17	1D		N/A	
CF	VALUE 18	1D		N/A	
CF	VALUE 19	1D		Bin Size	m
CF	VALUE 20	1D		Manual Yaw Correction	no = 0, yes = 1, unknown = 2

4.2.3 Description of fields - SBD

Data Fields	Sub Fields	Dimensions	Number Format	Description	Units
Timestamp	NO	1D	double	Timestamp (Matlab format)	days
B1	NO	2D	single	Velocity Profile from Beam 1	m/s
Amp	NO	2D	single	Amplitude Return Profile from Beam 1	Counts
Cor	NO	2D	single	Correlation Profile from Beam 1	N/A
Pressure	NO	2D	single	Instrument Depth from Pressure Gauge	m
CF	YES	2D	double	Instrument Configuration Tracking Data	Multiple (see TD_VALUE_n)
CF	VALUE 1	1D	'nCells'	Number of cells in the profile	
CF	VALUE 2	1D	'salinity'	Salinity	ppt
CF	VALUE 3	1D	'nSamples'	Number of samples	
CF	VALUE 4	1D	'cellSize'	Cell Size	m
CF	VALUE 5	1D	'blankingDistar	Distance to first cell	m
CF	VALUE 6	1D	'sampleRate'	Profile sampling rate	Hz
CF	VALUE 7	1D	'powerLevel'	Power Level	dB
CF	VALUE 8	1D	'velocityRange	Velocity range along beam	m/s
CF	VALUE 9	1D	'velocityPrecisi	Velocity precision	m/s
CF	VALUE 10	1D	'nPings'	Number of pings per ensemble	
CF	VALUE 11	1D	'pressure'	Pressure sensor installed	
CF	VALUE 12	1D	'temperature'	Temperature sensor installed	
CF	VALUE 13	1D	'ptpEnable'	PTP time tracking enabled	
CF	VALUE 14	1D	'txOffset'	Transmit offset time	s
CF	VALUE 15	1D	'soundVelocity	Velocity of sound	m/s
CF	VALUE 16	1D	'enablePTP'	PTP time tracking enabled	
CF	VALUE 17	1D	'N/A'	Depreciated Field	
CF	VALUE 18	1D	'fwVersion'	Firmware Version	
CF	VALUE 19	1D	'N/A'	Length of time that collection should run for	s
CF	VALUE 20	1D	'startCollectior	Seconds since Jan 1, 1970 00:00:00 GMT	s
CF	VALUE 21	1D	'startCollectior	Fractional seconds	
CF	VALUE 22	1D	'endCollection	Seconds since Jan 1, 1970 00:00:00 GMT	s
CF	VALUE 23	1D	'endCollection	Fractional seconds	
CF	VALUE 24	1D	'nSets'	Total number of data records in this file	
CF	VALUE 25	1D	'droppedSets'	Number of data records dropped due to read errors	
CF	VALUE 26	1D	'instrumentOff	Add this offset to the instrument time stamp to retrieve the corresponding platform time for a record	s
CF	VALUE 27	1D	'date'	Matlab Indicative Timestamp (GMT)	days
CF	Value 28	1D	'hostName'	Instrument Name	
CF	VALUE 29	1D		Location	UTM Zone 30 N, metres East
CF	VALUE 30	1D		Location	UTM Zone 30 N, metres Nortl
CF	VALUE 31	1D		Flagged as being recorded in BST, 1 = yes, 0 = no	
CF	VALUE 32	1D		Matlab Start Time (GMT)	
CF	VALUE 33	1D		Matlab End Time (GMT)	

4.2.4 Description of fields - AWAC

Data Fields	Sub Fields	Dimensions	Number Format	Description	Units
Timestamp	NO	1D	double	Timestamp (Matlab format)	days
B1	NO	2D	single	Velocity Profile from Beam 1	m/s
B2	NO	2D	single	Velocity Profile from Beam 2	m/s
B3	NO	2D	single	Velocity Profile from Beam 3	m/s
X	NO	2D	single	Velocity Profile in Instrument Coordinates (X)	m/s
Y	NO	2D	single	Velocity Profile in Instrument Coordinates (Y)	m/s
Z	NO	2D	single	Velocity Profile in Instrument Coordinates (Z)	m/s
Amp1	NO	2D	single	Amplitude Return Profile from Beam 1	Counts
Amp2	NO	2D	single	Amplitude Return Profile from Beam 2	Counts
Amp3	NO	2D	single	Amplitude Return Profile from Beam 3	Counts
Heading	NO	1D	single	Instrument Heading	degrees
Pitch	NO	1D	single	Instrument Pitch	degrees
Roll	NO	1D	single	Instrument Roll	degrees
Pressure	NO	2D	single	Instrument Depth from Pressure Gauge	m
CF	YES	2D*	double	Instrument Configuration Tracking fields	Multiple (see CF_VALUE_n)
CF	VALUE 1	1D		Bad Time Stamp Detected	1=Time Stamp Error, 0 = No Error
CF	VALUE 2	1D		Number of Pings Per Ensemble	
CF	VALUE 3	1D		MatlabTimestamp	days
CF	VALUE 4	1D		Coordinate System	2 = Instrument Beam Coordinates
CF	VALUE 5	1D		SoundSpeed	m/s
CF	VALUE 6	1D		Heading	degrees
CF	VALUE 7	1D		Pitch	degrees
CF	VALUE 8	1D		Roll	degrees
CF	VALUE 9	1D		Instrument Depth from Pressure Gauge	m
CF	VALUE 10	1D		Temperature	degrees C
CF	VALUE 11	1D		Number of Beams	
CF	VALUE 12	1D		Number of Bins	
CF	VALUE 13	1D		Sample Rate	Hz
CF	VALUE 14	1D		Location of first measurement Bin	m
CF	VALUE 15	1D		Location	UTM Zone 30 N, metres East
CF	VALUE 16	1D		Location	UTM Zone 30 N, metres North
CF	VALUE 17	1D		N/A	
CF	VALUE 18	1D		N/A	
CF	VALUE 19	1D		Bin Size	m
CF	VALUE 20	1D		Manual Yaw Correction	no = 0, yes = 1, unknown = 2

4.2.5 Description of fields - CONT

Data Fields	Sub Fields	Dimensions	Number Format	Description	Units
Timestamp	NO	1D	double	Timestamp (Matlab format)	days
B1	NO	2D	single	Velocity Profile from Beam 1	m/s
Amp1	NO	2D	single	Amplitude Return Profile from Beam 1	Counts
Pitch	NO	1D	single	Instrument Pitch	degrees
Roll	NO	1D	single	Instrument Roll	degrees
Pressure	NO	1D			
CF	YES	2D *	double	Instrument Configuration Tracking fields	Multiple (see CF_VALUE_n)
CF	VALUE 1	1D		Bad Time Stamp Detected	
CF	VALUE 2	1D		Number of Pings Per Ensemble	
CF	VALUE 3	1D		MatlabTimestamp	days
CF	VALUE 4	1D		ErrorCode	see RDI ADCP manual
CF	VALUE 5	1D		SoundSpeed	m/s
CF	VALUE 6	1D		Heading	degrees
CF	VALUE 7	1D		Pitch	degrees
CF	VALUE 8	1D		Roll	degrees
CF	VALUE 9	1D		Instrument Depth from Pressure Gauge	m
CF	VALUE 10	1D		Temperature	degrees C
CF	VALUE 11	1D		Number of Beams	
CF	VALUE 12	1D		Number of Bins	
CF	VALUE 13	1D		Sample Rate	Hz
CF	VALUE 14	1D		Location of first measurement Bin	m
CF	VALUE 15	1D		Location	UTM Zone 30 N, metres East
CF	VALUE 16	1D		Location	UTM Zone 30 N, metres North
CF	VALUE 17	1D		N/A	
CF	VALUE 18	1D		N/A	
CF	VALUE 19	1D		Bin Size	m
CF	VALUE 20	1D		Manual Yaw Correction	no = 0, yes = 1, unknown = 2

Table 1: Instruments Used

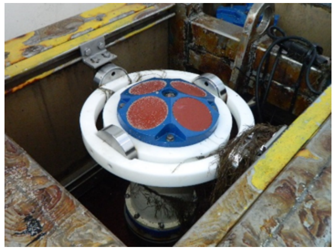
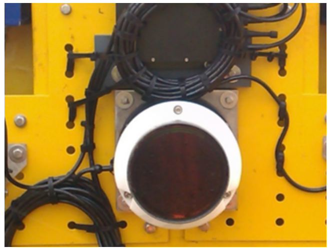
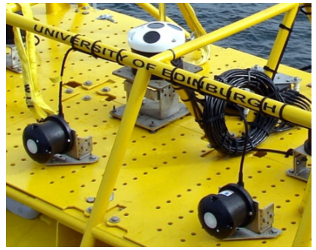
Instrument Name	**ADCP**	**AWAC**	**CONT**	**SBD**
Instrument Type	Divergent Acoustic Doppler Profiler (D-ADP)	Divergent Acoustic	Single-Beam Acoustic Doppler Profiler (SB-ADP)	Single-Beam Acoustic Doppler Profiler (SB-ADP)
Manufacturer	Teledyne RDI	Nortek AS	Nortek AS	Nortek AS
Sample Rate (Hz)	0.5 (typical), 1, 2	2 (typical), 4	1	2 , 4
Acoustic Freq (kHz)	600	1000	198	1000
Bin Size (m)	1 (typical), 1.5	1 (typical), 0.5	1,4,5,10	0.4 (typical), 0.5, 1
No. of Transducers	4	3+1 Vert	1	1
Location	Seabed	Turbine	Turbine	Turbine
Orientation	Upwards	Upwards	Rearwards	Multiple
				

Table 2: Indexing Fields (System State)

Column	**1**	**2**	**3**	**4**	**5**
Field Units	Timestamp (Days) Matlab format	Tidal State 1 = Ebb 0 = Flood	Reference Velocity (m/s) Depth averaged across rotor plane	Turbine Yaw Angle (degrees) to North	Turbine Generating 1 = Generating, 0 = Not Generating

Table 3: Data Summary

Measurement Type	Instrument Type	Name	Sample Rate and Process State			Dates		Position	
			0.5-4Hz	0.5-4Hz	5 Mins			UTM	
			RAW	QC	DA	From	To	mE	mN
Tidal Current	ADCP	ADCP01_NW_Dep0	y	y	y	18 Feb 2013	20 Mar 2013	30N 511072.765	6555341.854
Tidal Current	ADCP	ADCP01_NW_Dep1	y	y	y	01 Jun 2013	18 Jul 2013	30N 511054.2	6555328.9
Tidal Current	ADCP	ADCP01_NW_Dep2	y	y	y	18 Jul 2013	13 Aug 2013	30N 511067.011	6555352.935
Tidal Current	ADCP	ADCP01_NW_Dep3	y	y	y	15 Oct 2013	29 Nov 2013	30N 511068	6555352
Tidal Current	ADCP	ADCP01_NW_Dep5	y	y	y	19 Jun 2014	03 Aug 2014	30N 511072	6555354
Tidal Current	ADCP	ADCP02_NW_Dep5	y	y	y	06 Jul 2014	17 Aug 2014	30N 511052	6555394
Tidal Current	ADCP	ADCP02_SE_Dep1	y	y	y	05 Jun 2013	18 Jul 2013	30N 511151.1	6555241.1
Tidal Current	ADCP	ADCP02_SE_Dep2	y	y	y	18 Jul 2013	24 Aug 2013	30N 511155.019	6555262.252
Tidal Current	ADCP	ADCP02_SE_Dep3	y	y	y	15 Oct 2013	27 Nov 2013	30N 511151.3	6555241.8
Tidal Current	ADCP	ADCP02_SE_Dep4	y	y	y	04 Apr 2014	12 Jun 2014	30N 511147	6555249
Tidal Current	ADCP	ADCP03_SE_Dep1	y	y	y	19 Jun 2014	03 Aug 2014	30N 511142	6555260
Tidal Current	ADCP	ADCP_D1	y	y	y	23 Jun 2011	27 Jul 2011	30N 511647.9	6554397
Tidal Current	ADCP	ADCP_D2	y	y	y	23 Jun 2011	27 Jul 2011	30N 511647.9	6554397
Tidal Current	SBD	SBD01	y	y	y	23 Jun 2014	17 Oct 2014	30N 511111.517	6555307.693
Tidal Current	SBD	SBD02	y	y	y	05 Mar 2013	04 Aug 2014	30N 511111.517	6555307.693
Tidal Current	SBD	SBD03	y	y	y	22 Feb 2013	13 Aug 2014	30N 511111.517	6555307.693
Tidal Current	SBD	SBD05	y	y	y	05 Mar 2013	22 Sep 2014	30N 511111.517	6555307.693
Tidal Current	SBD	SBD08	y	y	y	04 Oct 2013	22 Oct 2014	30N 511111.517	6555307.693
Tidal Current	SBD	SBD10	y	y	y	10 Apr 2014	13 Aug 2014	30N 511111.517	6555307.693
Tidal Current	SBD	SBD11	y	y	y	21 Feb 2013	09 Nov 2013	30N 511111.517	6555307.693
Tidal Current	SBD	SBD12	y	y	y	22 Jul 2014	22 Oct 2014	30N 511111.517	6555307.693
Tidal Current	SBD	SBD14	y	y	y	16 Apr 2014	04 Jul 2014	30N 511111.517	6555307.693
Tidal Current	SBD	SBD16	y	y	y	22 Feb 2013	22 Oct 2014	30N 511111.517	6555307.693
Tidal Current	SBD	SBD18	y	y	y	21 Feb 2013	05 Mar 2013	30N 511111.517	6555307.693
Tidal Current	AWAC	AWAC	y	y	y	08 Mar 2012	31 Jul 2014	30N 511111.517	6555307.693
Tidal Current	SBD	CONT	y	y	y	08 Mar 2012	25 Oct 2013	30N 511111.517	6555307.693

4.3 Instrumentation

Instrumentation technology and availability developed during the course of the project. Equipment is now available, offering definitive advantages for tidal site characterisation, that was not available at project commencement and the procurement stage. In the latter stages of ReDAPT some of these advances were trialled and will be reported upon in subsequent publications.

Instrument configurations were not fixed. Configuration changed between deployments and in some cases during individual campaigns. Instrument configuration should be taken into account during any further data analysis.

Instruments mounted on the turbine (SBD, AWAC, CONT) will change orientation as the turbine is moved in yaw on its tripod. Contact Brian.Sellar@ed.ac.uk for more information.

4.3.1 Instrumentation Types

Multiple instruments were deployed including:

- "Standard" four-beam Diverging Acoustic Doppler Profilers (D-ADPs) (or *ADCPs* as they are commonly referred to);
- Three-beam plus vertical D-ADPs of the *AWAC* variant
- Multiple prototype single-beam ADPs (SB-ADP) herein referred to as Single Beam Doppler devices (SBDs).

4.3.2 TYPE 1. Single Beam Acoustic Doppler Profiling (SB-ADP)

The Nortek AD2CP platform upon which their supplied Mark I prototype 1MHz SBDs operate is a useful tool when integrating ADP instrumentation with a commercial scale tidal turbine. Robust remote access to the instruments over TCP/IP communications (internet) is used along with accurate timing control through the use of an external broadcast Precision Time Protocol (PTP) clock. The inclusion at the request of the UoE of an Application Program Interface (API) exposes the instruments to control via MATLAB which allows for a high level of end-user control where required.

Application Notes

Acoustically, useful instrument range was found at this site to be limited to approximately 17m. This was increased to approximately 20m through upgraded power supplies and grounding methods. This profiling range was found to be suitable for inflow velocity assessment during periods of turbine non-generation. Whilst generating, particularly at rated power (which this turbine quickly ramps up to) the range is not sufficient to penetrate the region of upstream-affected flow.

The instruments sampling rate of 4Hz (updated from 2Hz during the campaigns and recently increased to 16Hz in newer variants but not used here) allows more of the frequency range of velocity spectra to be assessed compared to similar equipment at the time of use. Their small size simplified instrument integration with the turbine and instrumentation package frames.

The presence of a possible velocity bias (underestimation as compared to sea-bed mounted D-ADPs) of the order of 5% continues to be investigated.

Instrument reliability and feature set increased over the course of the project due to supplier provided firmware and software updates.

Instruments were robust enough to survive prolonged (up to 3 months) deployments.

4.3.3 TYPE 2. Diverging Beam Acoustic Doppler Profiling (D-ADP)

Two four-beam Teledyne RDI Workhorse Sentinel 600kHz were used and were placed where feasible within the wider project both upstream and downstream of the turbine approximately in the streamwise flow direction.

Application Notes

Data capture success was 93% with a single deployment failing due to a data writing error. The instruments performed well and captured seabed to surface profiles of velocity in 1.5m and 1m (more commonly) bins at various configured sample rates from 0.5Hz, 1Hz and 2Hz.

Low sampling rates were chosen (due to legacy equipment memory storage limits) to maximise simultaneous operation with the turbine to meet multiple project deliverables.

Figure 3: Multiple ADCP D-ADP's quayside in Orkney, UK prior to deployment in 2014

These instruments survived prolonged (3 months) deployments with no maintenance issues.

A three-beam Nortek AWAC 1000kHz (shown in centre of right-most image in Table 1) was installed at the top rear of the turbine and was configured primarily in current-measurement mode (as opposed to wave tracking mode).

4.4 Deployment and Retrieval of Seabed Mounted Instrumentation

Multiple deployment and recovery methods were used and optimised within the broader turbine deployment and recovery operations. Instrument deployment locations are shown in Table 3.

4.4.1 Distant from turbine (>250m)

Deployments and recoveries of the type routinely employed by EMEC (and others) worked well. They involved local vessels with excellent site knowledge and reasonable day rates. Frames of approximately 600kg mass fabricated from stainless steel worked well. No ROV was required in their deployment or recovery as small buoys attached to side-attached clump weights with trailing ground lines could be used. Loose stainless steel gimbals were used.

4.4.2 Close to turbine (<250m)

Where more accurate positioning of the seabed frames was required (either due to test specification or risk to other assets) Remotely Operated Underwater Vehicles (ROV) proved useful whilst adding significant cost to the operations. Through the use of an ROV two seabed instrument packages, for example, were deployed approximately 45m from the turbine to within $\pm$ 5m.

Custom deployment frames (see Figure 3) were successfully designed to minimise frame movement on the seabed, provide adequate space for extended battery and communications housings and to allow the installation of experimental damped instrument gimbals to minimise pitch and roll of the instruments whilst allowing an initial settling to near-vertical upon deployment.

4.5 Instrumentation Platforms

Two major instrumentation platforms were designed and deployed. Through negotiation with the turbine developers two areas on the machine were assigned for use by UoE: an area at the top and rear of the nacelle and the back face of the turbine thruster unit to within approximately 0.5m of the outer edge. The two frames, Edinburgh Subsea Instrumentation Platform -1 (ESIP-1) and ESIP-2 (top and rear respectively) are shown in Figures 4 and 5.

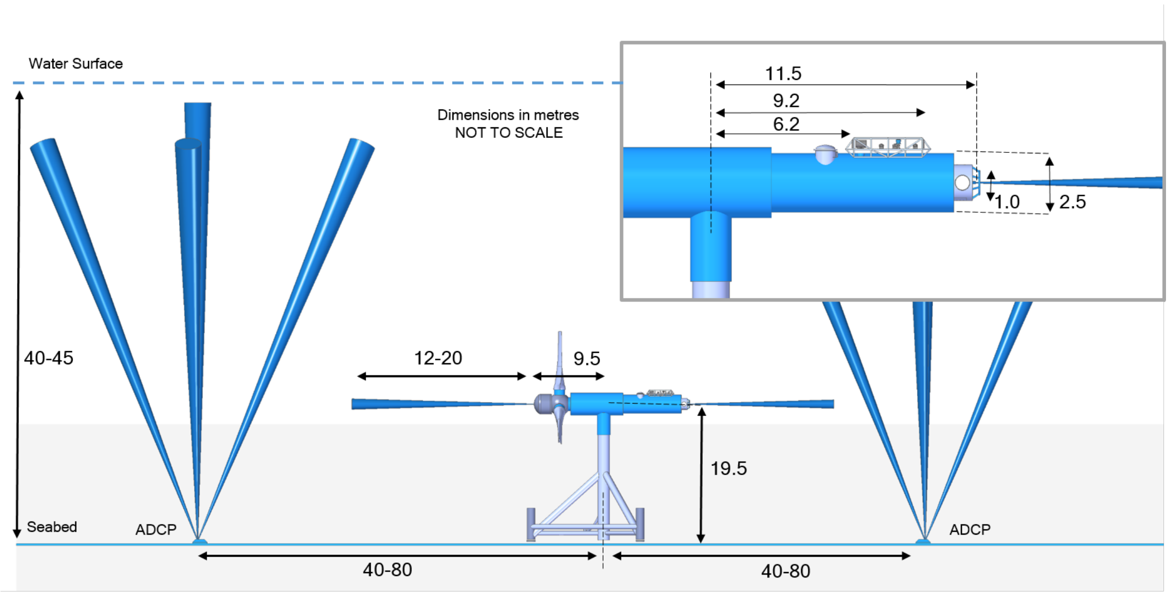
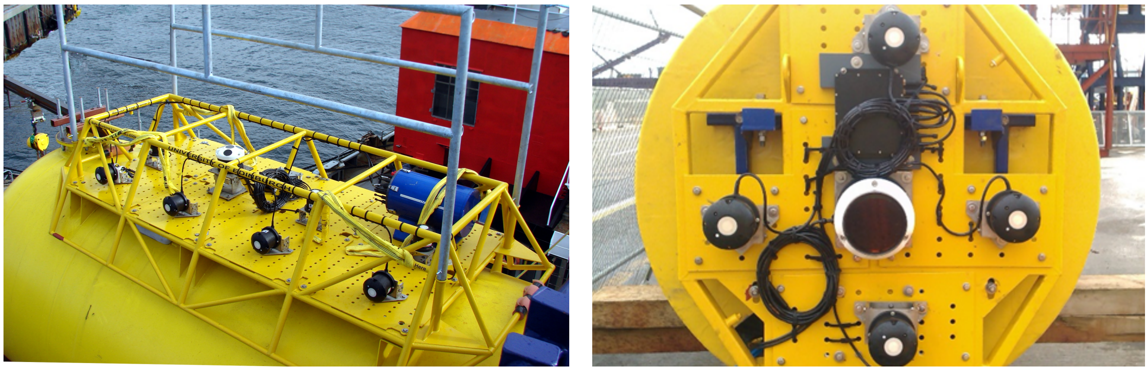


Figure 4: Schematic (not to scale) of the turbine, upstream and downstream ADCPs and ESIP-1 and ESIP-2 mounting positions.



(a) Photograph of ESIP-1 prior to a turbine deployment.

(b) Photograph of ESIP-2 taken summer 2014 ready for deployment.

Figure 5: ESIP-1 and ESIP-2 Instrument Frames

4.6 Data Management

A lot of work has gone into the acquisition of this data set. Designing instrumentation systems for the marine environment, transferring data, converting, pre-processing and sharing large volumes of multi-format, multi-configured data within a moving IT environment (hardware and software) was an expensive task.

Instrumentation was controlled in real-time (over the turbine communication cable) remotely by the University of Edinburgh and the data saved to the local servers on the EMEC, Eday substation. This was routinely downloaded over the limited bandwidth from this location and backed up to UoE Engineering deptarment servers.

Proprietary data was converted to a format that could be read by Matlab from within which all processing was carried out. In most cases this data had to be converted manually, albeit in batches.

Data management was originally conducted internally between project partners. Latterly a plan for use by the wider community beyond ReDAPT developed. This should have been integrated from project outset and has delayed the release of the data.

5 Work Completed and Opportunities for Collaboration

A comprehensive site characterisation for the turbine deployment site within the Fall of Warness has been carried out across several years and all seasons. Mean flows and turbulence metrics have been shown to vary significantly between Flood and Ebb tides. Of particular note are the differing velocity depth profile forms. Turbulence Intensity and Streamwise Lengthscales vary significantly between tidal cycles and show intra-cycle dependency on flow acceleration. Importantly, the presence of waves is shown to clearly impact on all of these metrics. Inter-instrument comparisons have been conducted as have sensitivity studies to various data processing stages.

The University of Edinburgh continues to analyse this data set. Ongoing efforts, in addition to improving provision of turbulence characterisation metrics already disseminated, are focused on the following areas:

- Wave measurement techniques at tidal energy sites
- Enhanced deployment and retrieval methodologies for seabed deployed equipment and peripheral enhancements and modifications
- Wave-current interaction
- Lengthscale analysis, particularly sensitivity of lengthscale distributions to site conditions
- Advanced C-ADP

For further information please see the ReDAPT Technical Report: MD3.8 Tidal Site Characterisation [11] or contact Brian.Sellar@ed.ac.uk

PDF LINK: ReDAPT Technical Report: MD3.8 Tidal Site Characterisation
(URL: `http://redapt.eng.ed.ac.uk/index.php?p=library_redapt_reports`)

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