Nortek European Users Symposium Oslo, 2010

ADCP monitoring – seagen tidal turbine

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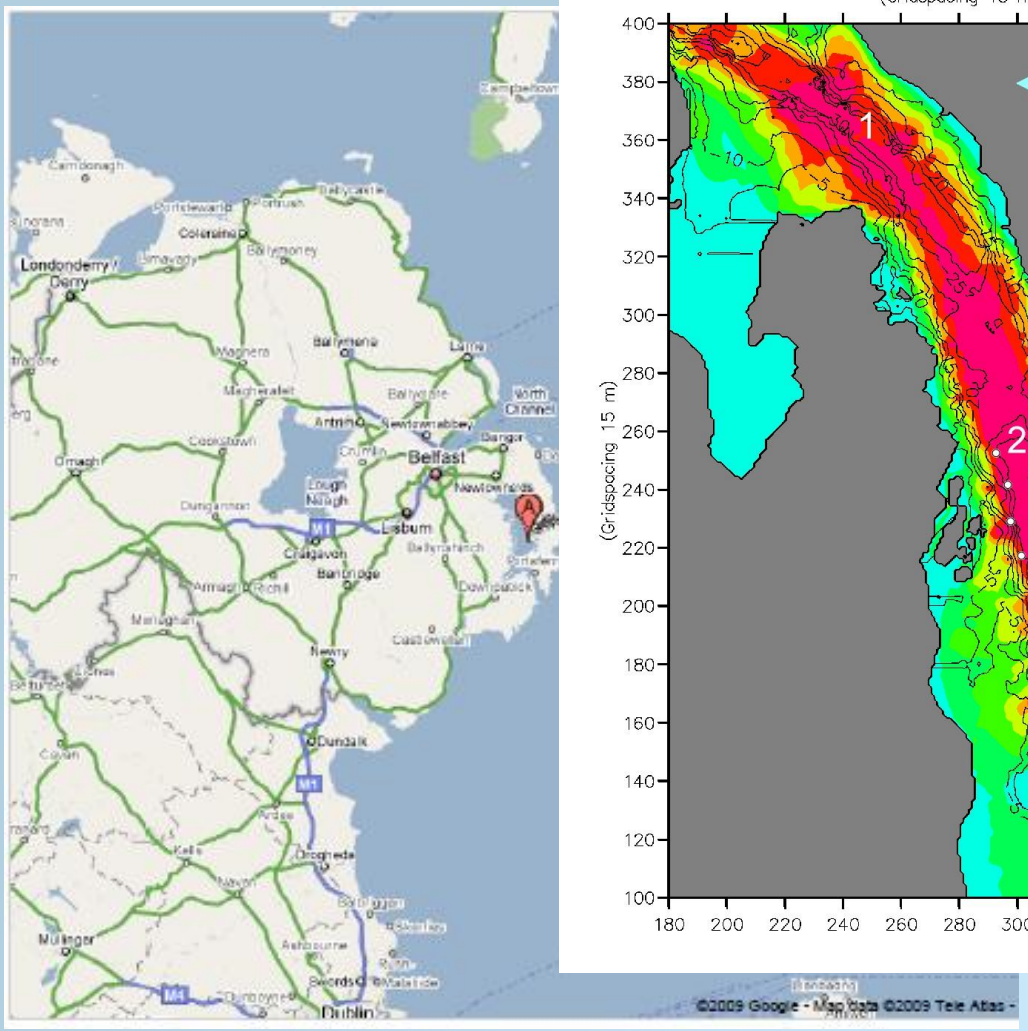
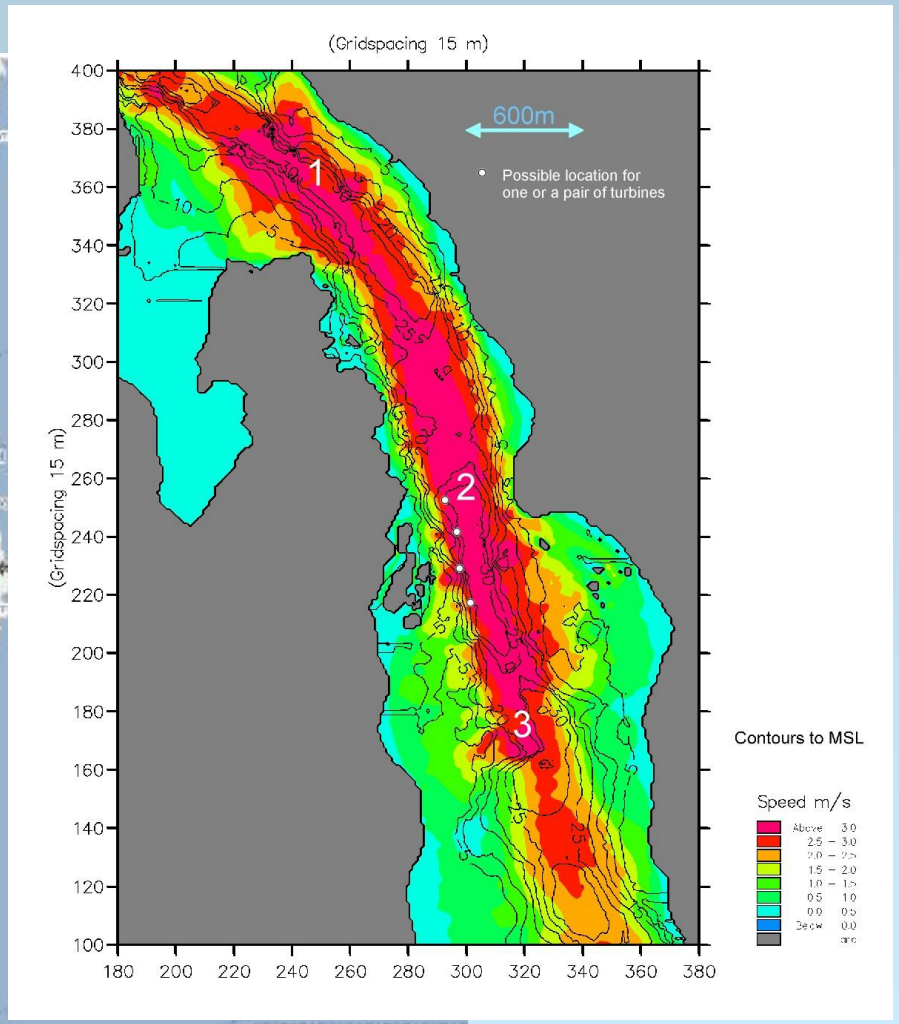
Agenda

- Seagen Project
  - ADCP Monitoring for Seagen
    - Resource Assessment
    - Environmental Monitoring
    - Performance Assessment
- 10th Scale Wake Investigation of HATT
  - Preliminary Methodology/Results

Tidal - Strangford Lough



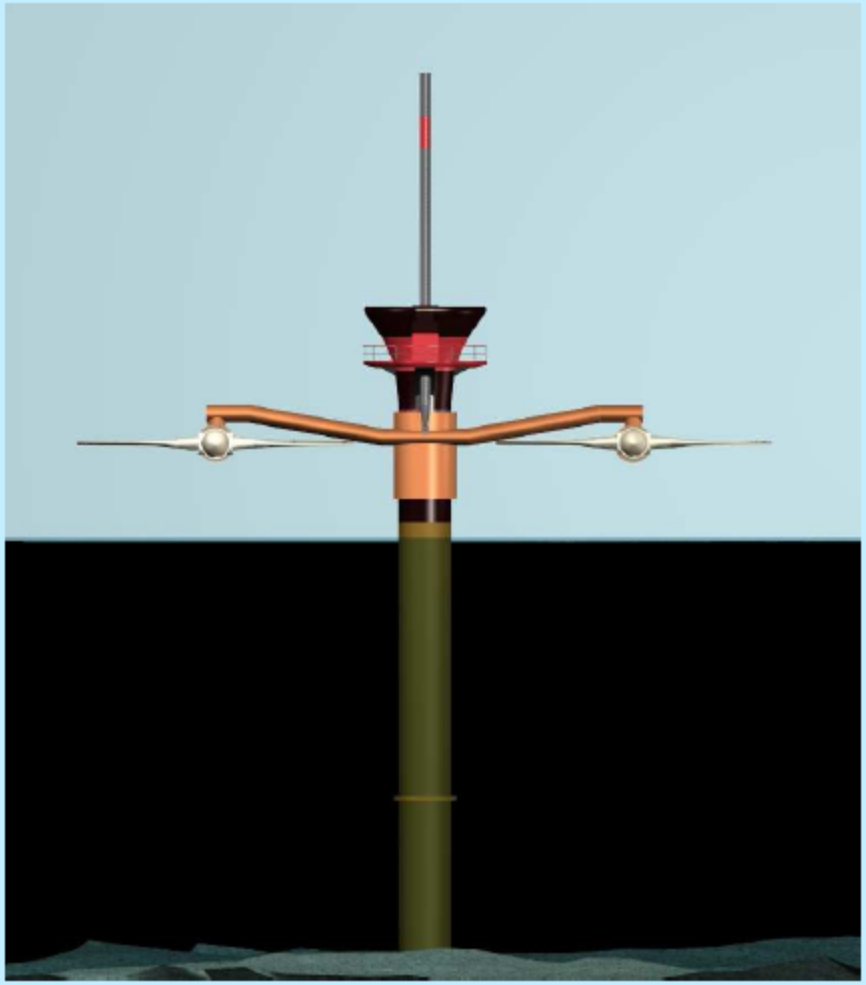


Marine Current Turbines Ltd - Seagen

SeaGen Prototype

Some key features:-

- 2 x 600kW rotors:16m diameter
- rotors and nacelles raised above sea level for maintenance and easy replacement
- transformer and electrical connection to grid in accessible and visible housing at top of pile
- 180 degree pitch control allows efficient rotor operation with bi-directional flow
- deployment in arrays or "farms". of hundreds of turbines



Seagen Deployment

SeaGen installation (MCT)

SeaGen – Cross Arm and Rotors

Tidal Energy – Seagen & QUB

- Tidal Resource and Site Assessments 2004
- Installation ADCP monitoring 2008
- Environmental Monitoring 2006-present
  - Pre and Post Deployment Evaluation
    - Benthic Studies
    - Current Mapping and Evaluation
- Performance Monitoring 2009-2010
  - Resource Characterisation
  - Device Classification

ADCP monitoring

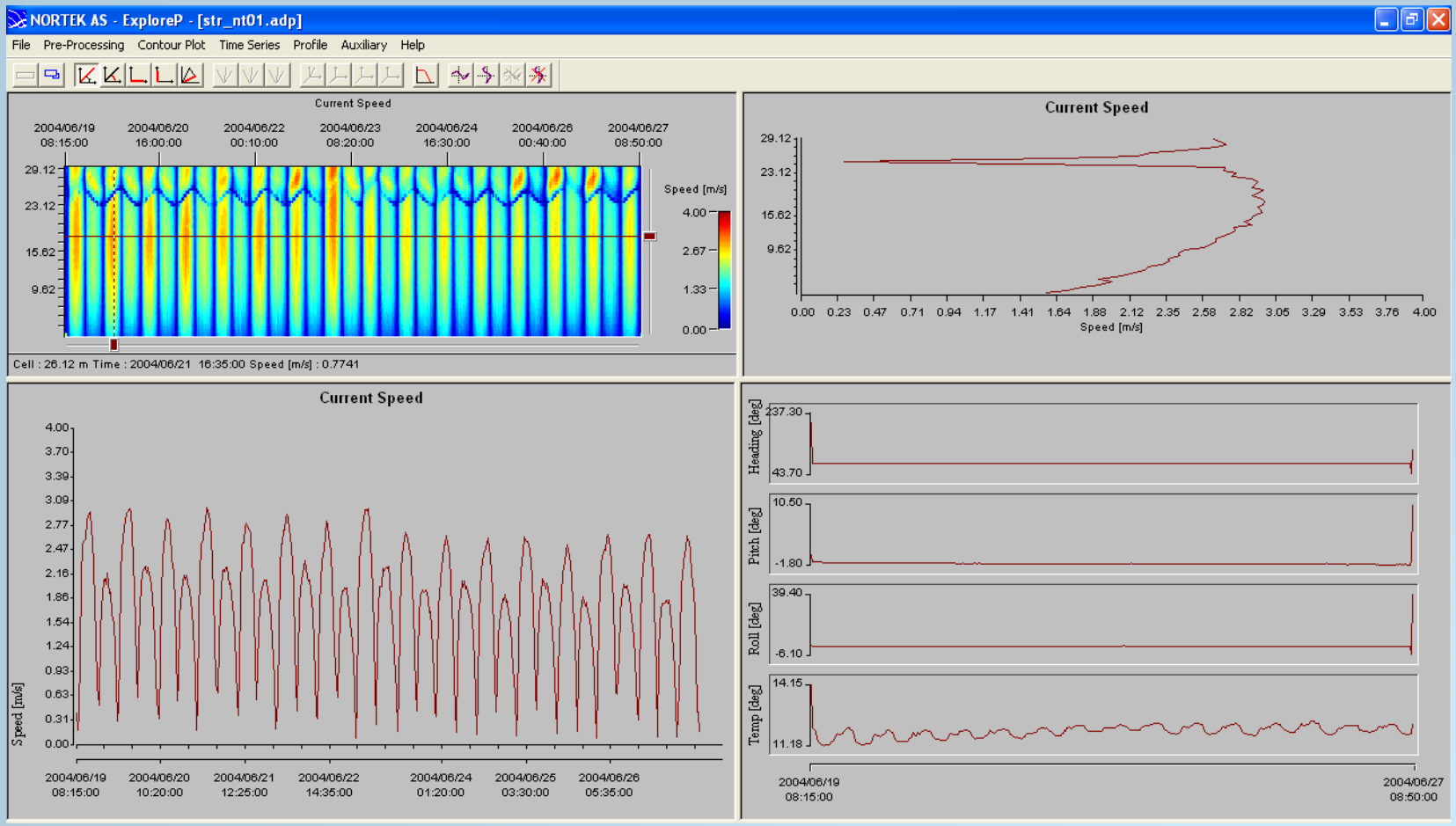
•Hemisphere V110 DGPS antennae

•ADCP vessel mounting

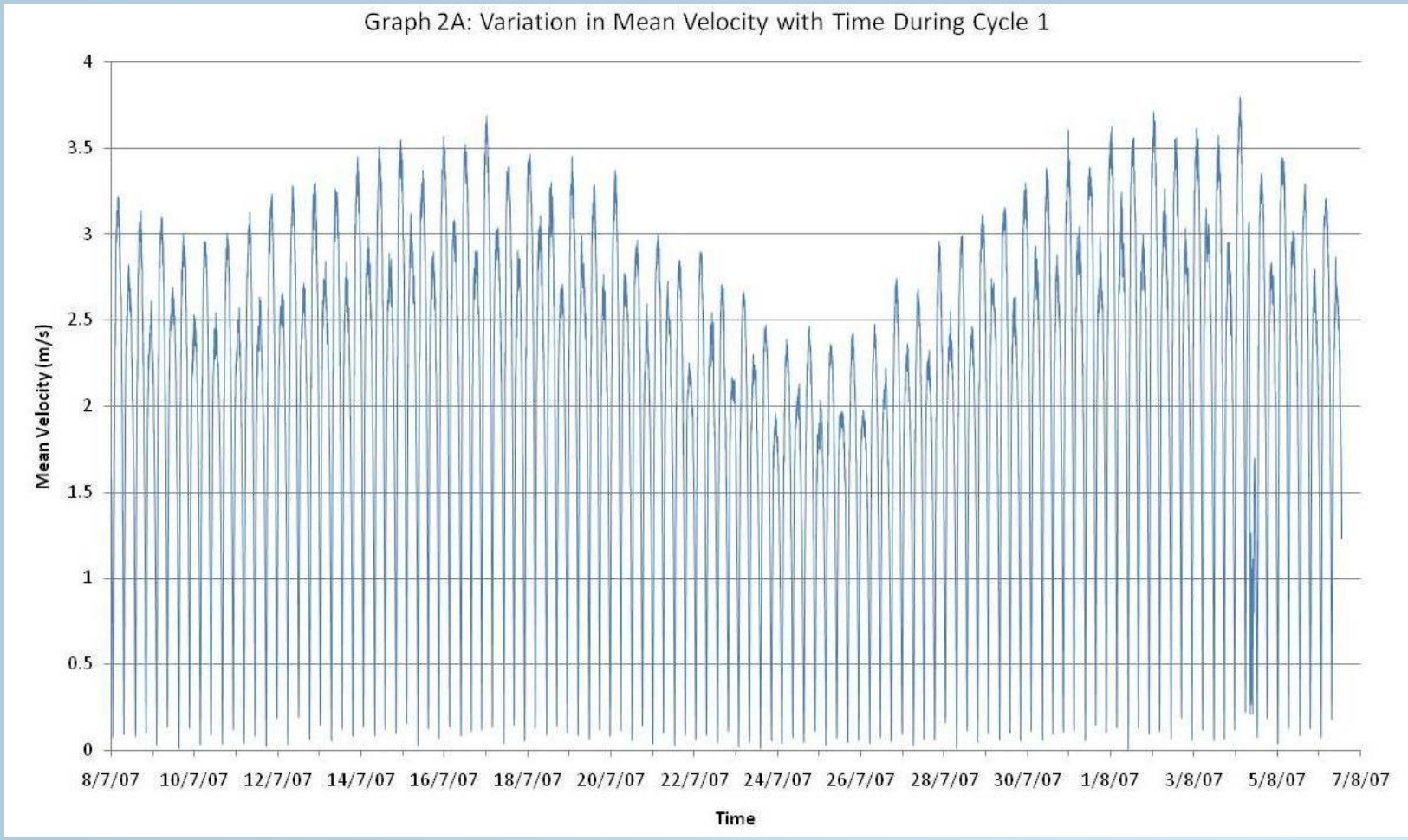
•Cuan Shore monitoring vessel

•Bottom-mounted ADCP frame

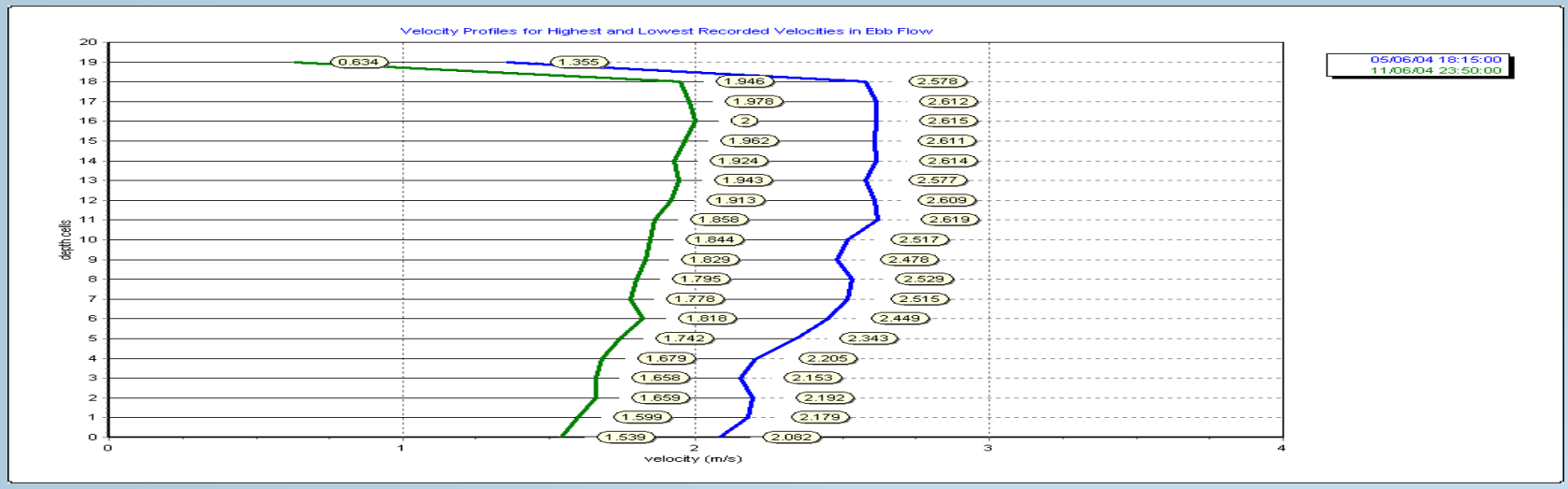
Site Assessments – AWAC 1MHz

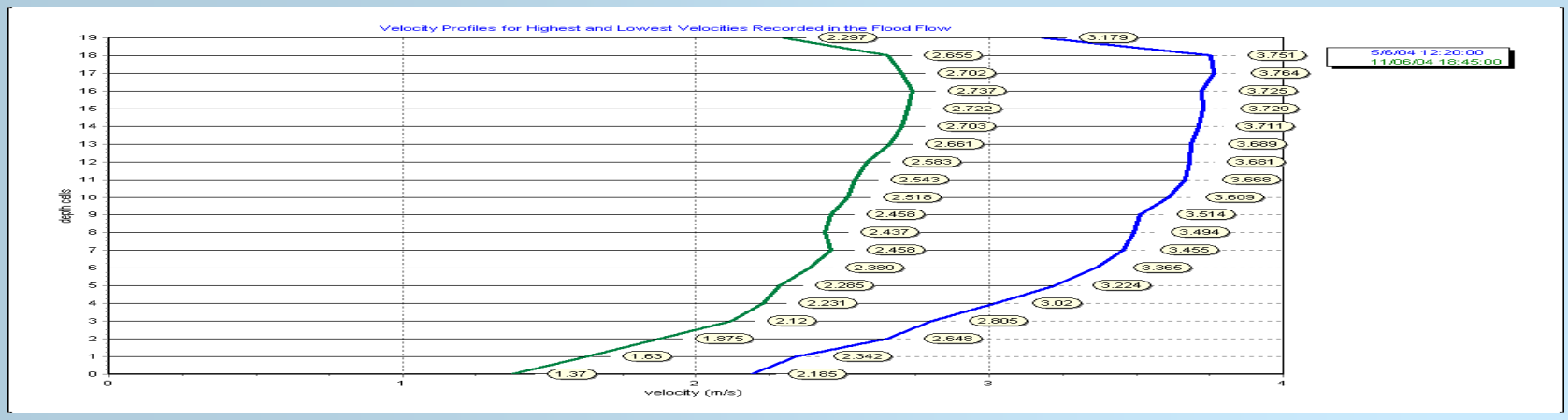


Resource Assessment



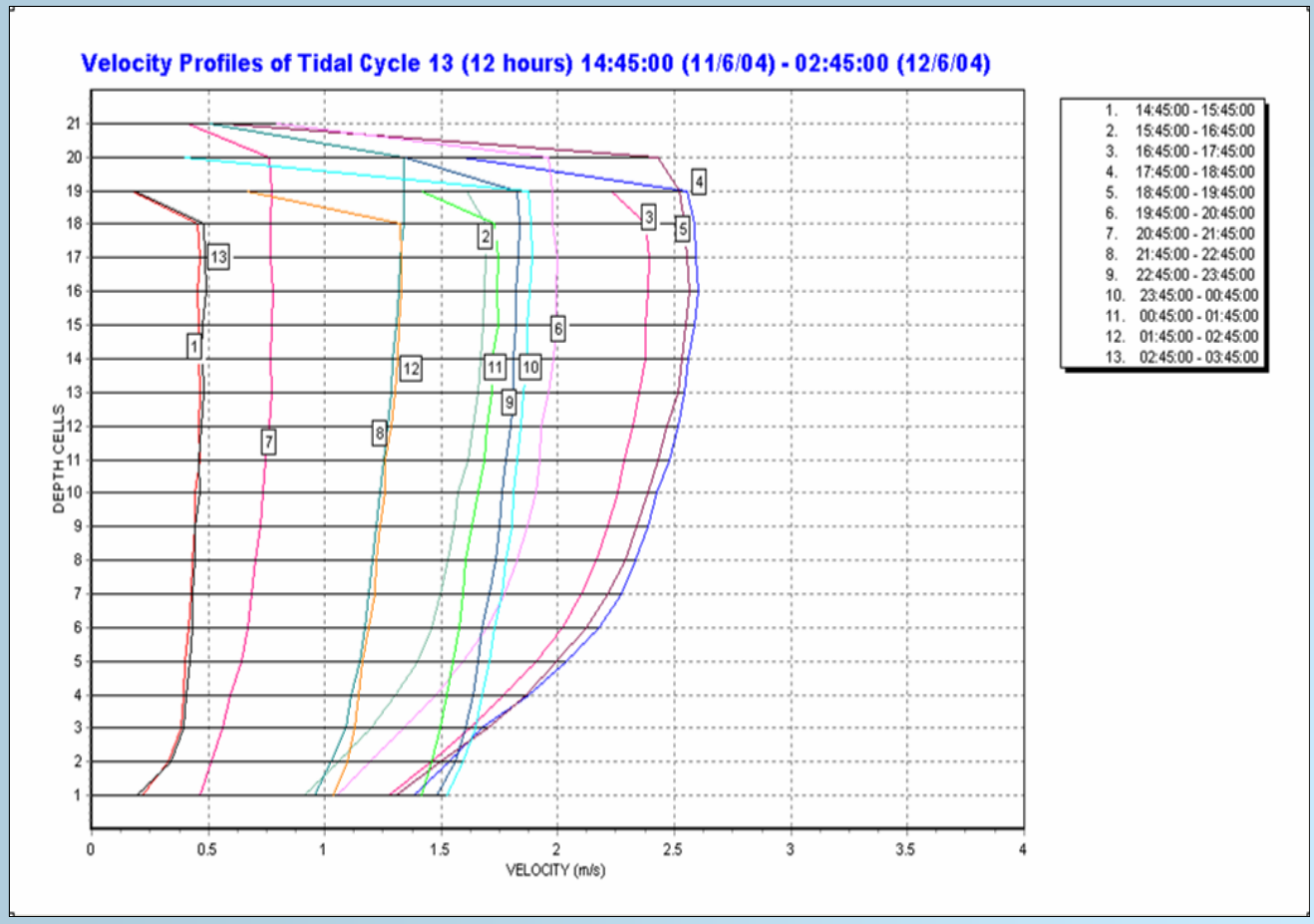
Flood/Ebb Velocities



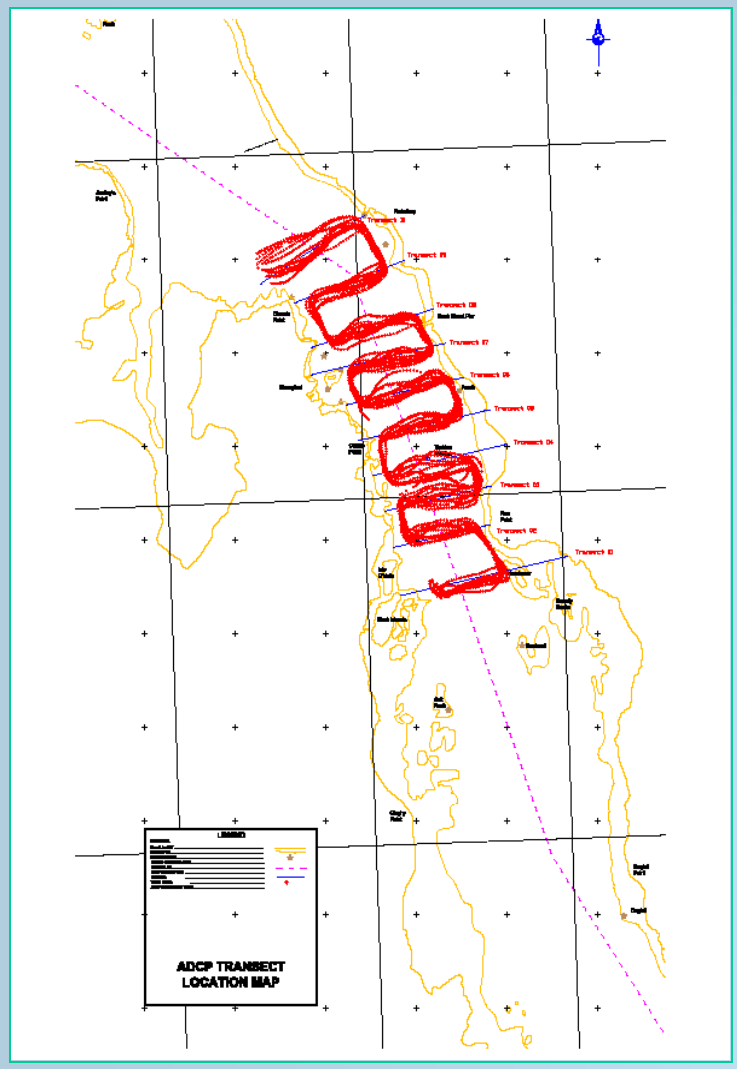


ADCP Data Analysis

➢ Resource Characterisation

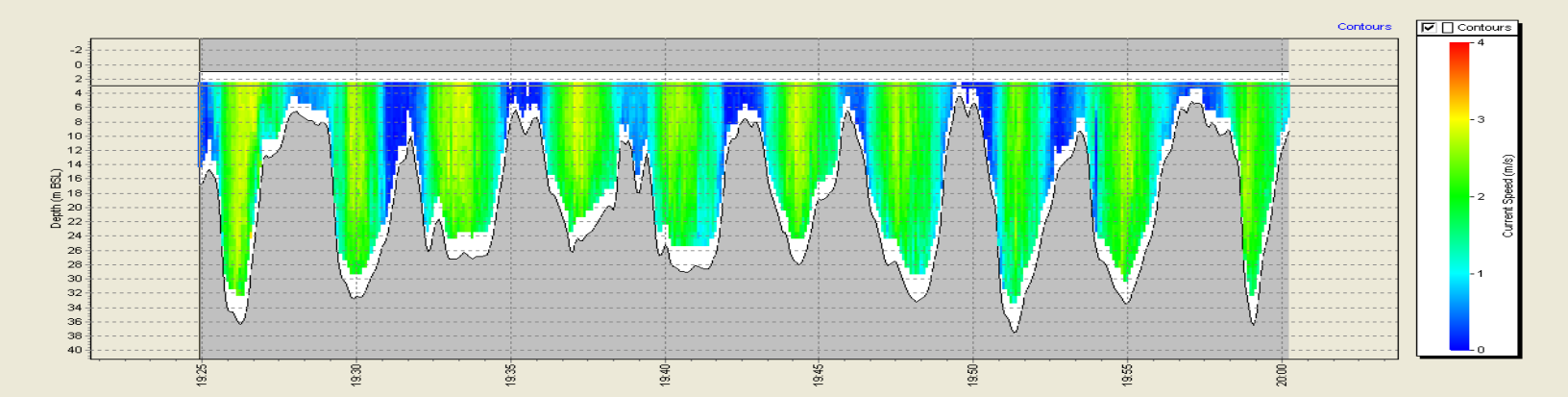


Full tidal survey - vessel mounted ADCP

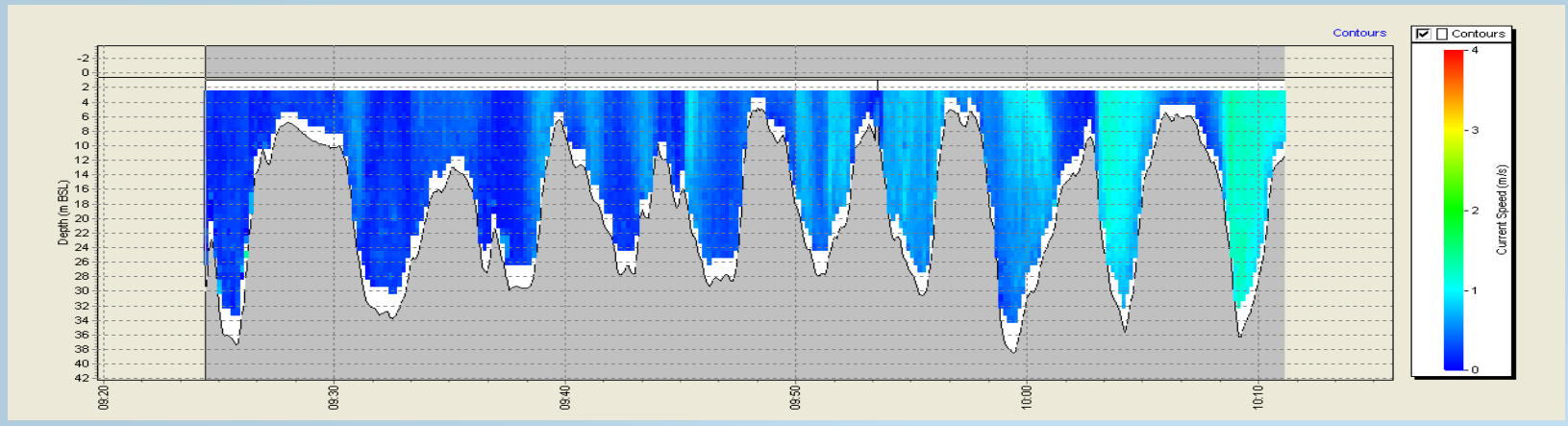


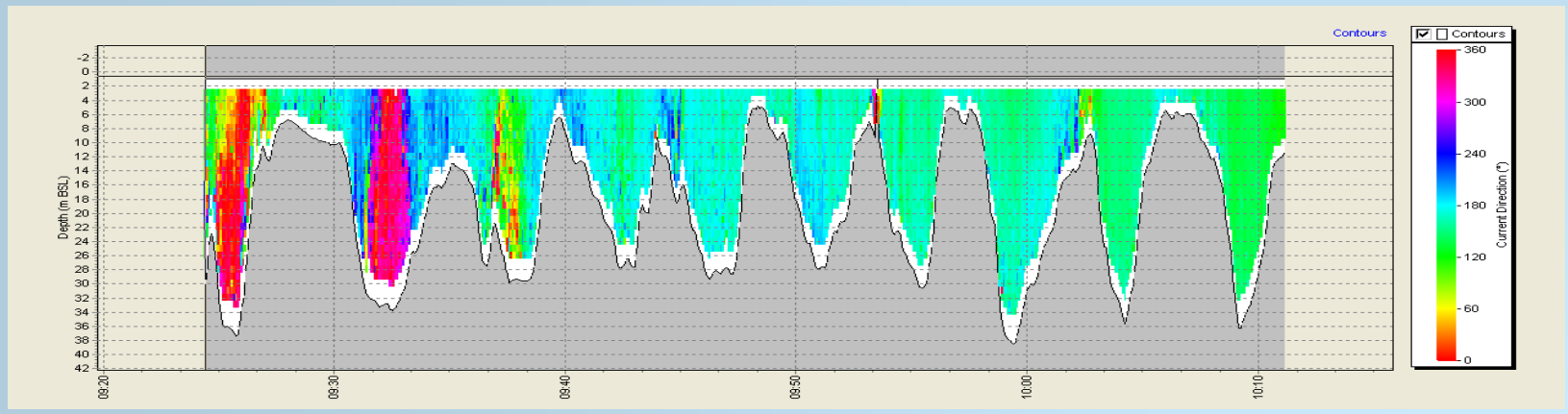
- Full Lough Survey
  - 10 transects (2000m)
  - 1 transect/hour
  - Full tidal cycle – 13 hours
  - Neap, Mid and Spring Tides
  - 8 pings/ensemble
  - Ambiguity velocity 8m/s
- Turbulence Survey
  - 6 transects
  - 150m apart
  - 1 ping/ensemble
  - Slow vessel speed

Water Velocity and Direction Contour for All 10 Transects: HW-3

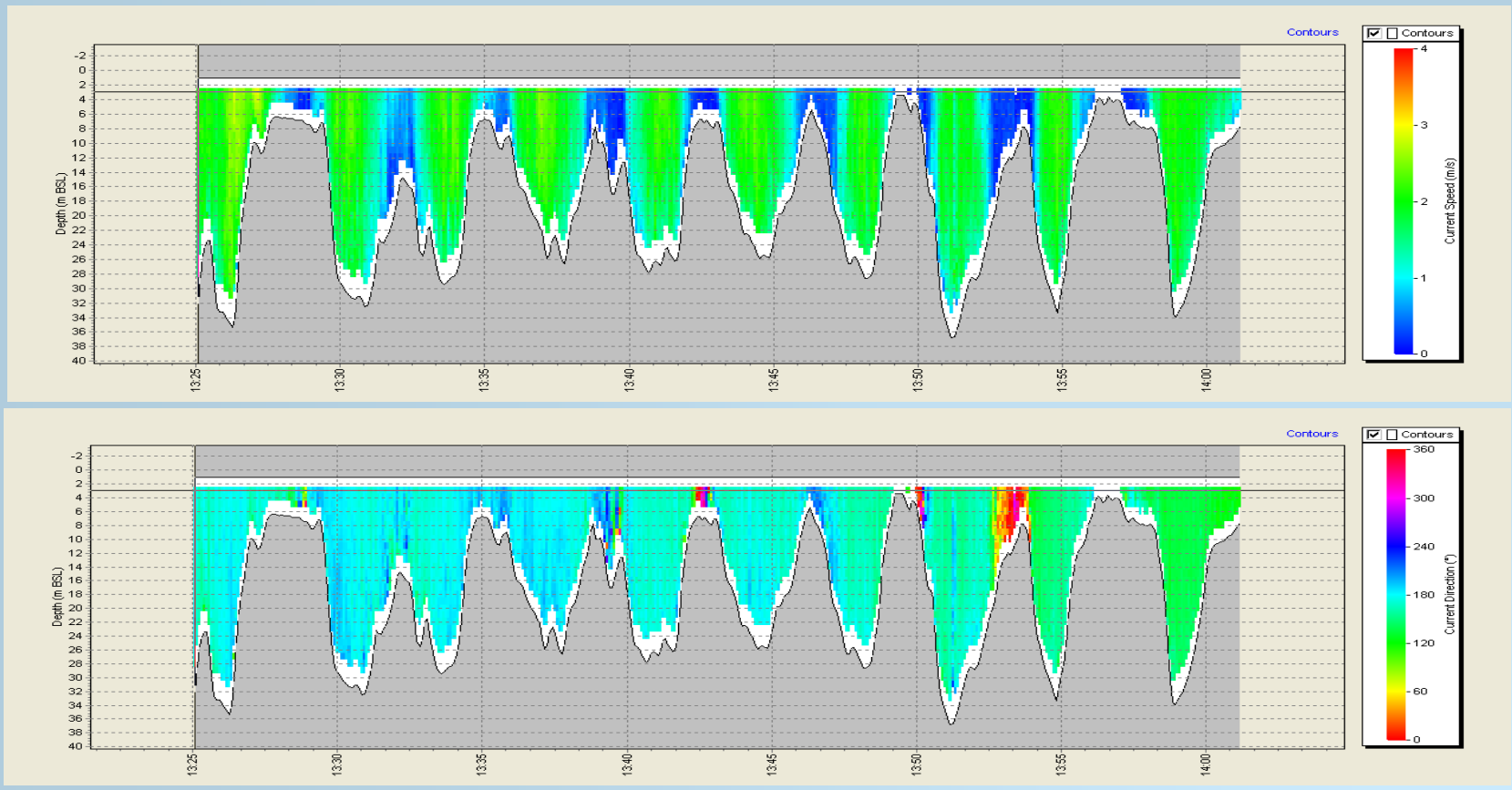


Water Velocity and Direction Contour for All 10 Transects: HW+0





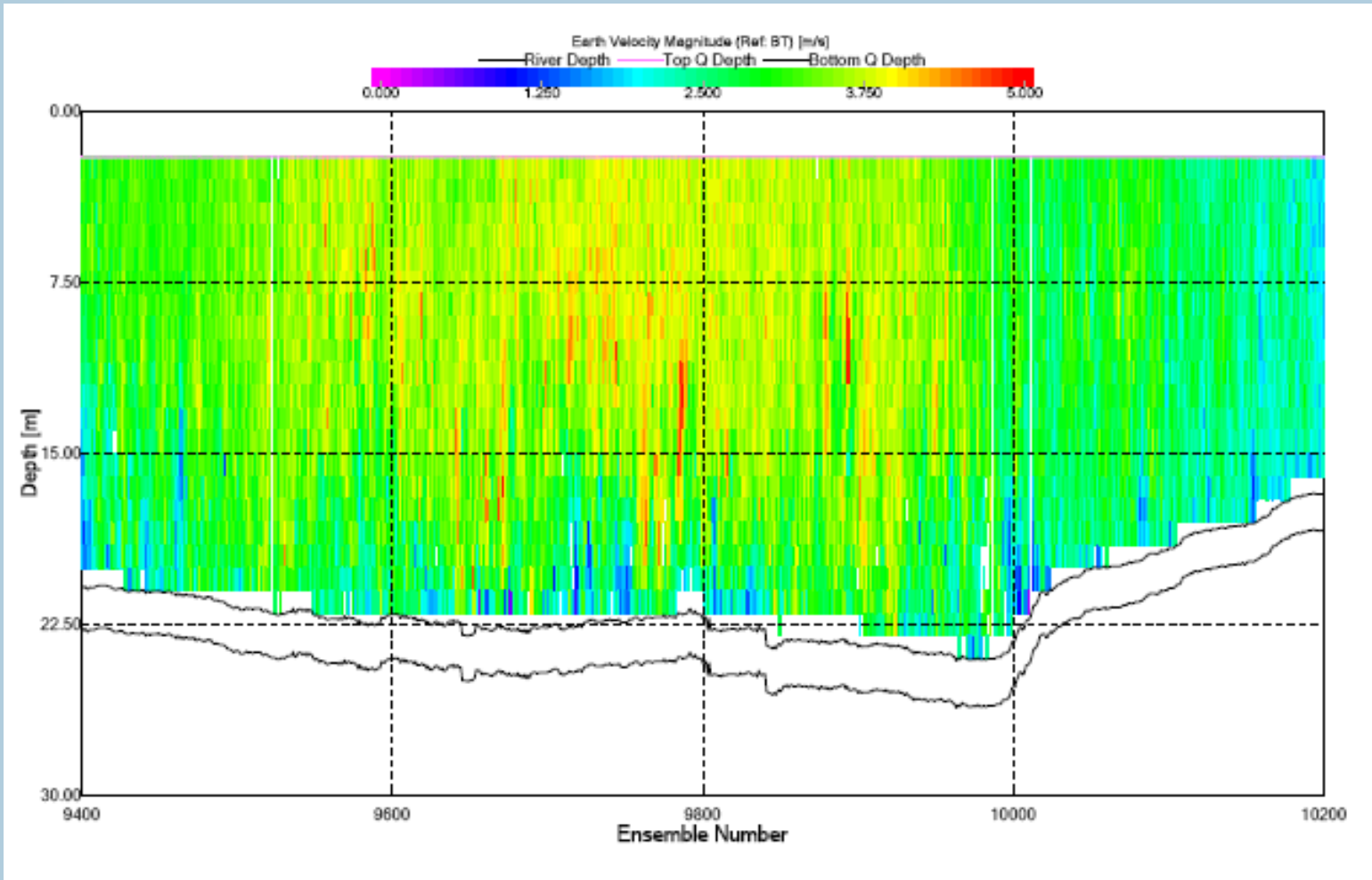
Water Velocity and Direction Contour for All 10 Transects: HW+3



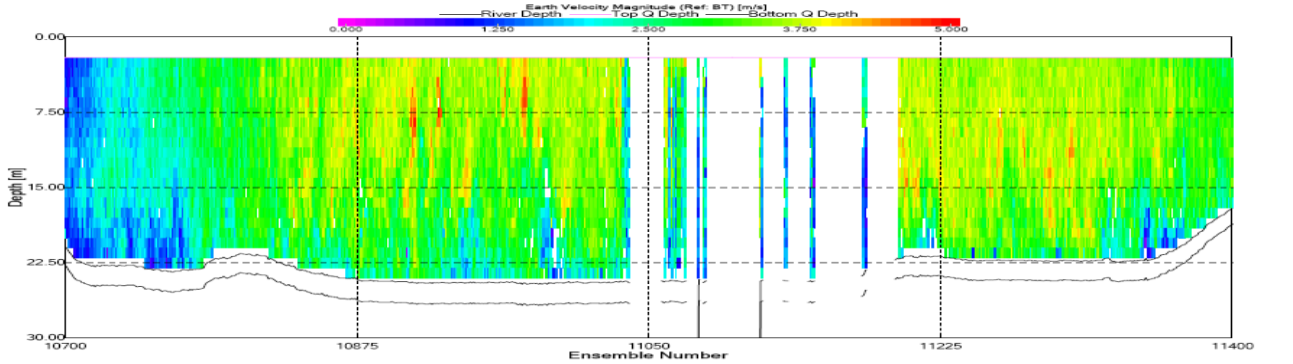
SeaGen – vortices behind pile

Turbulence

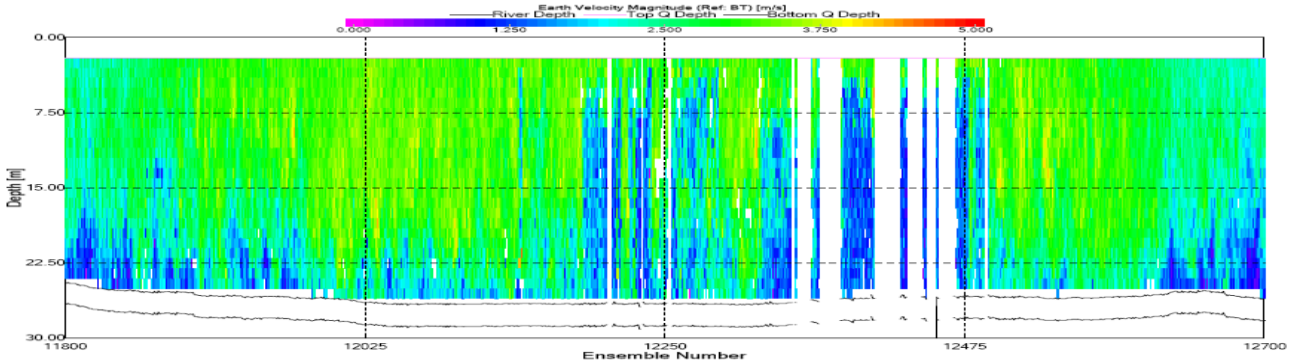
Turbulence Monitoring



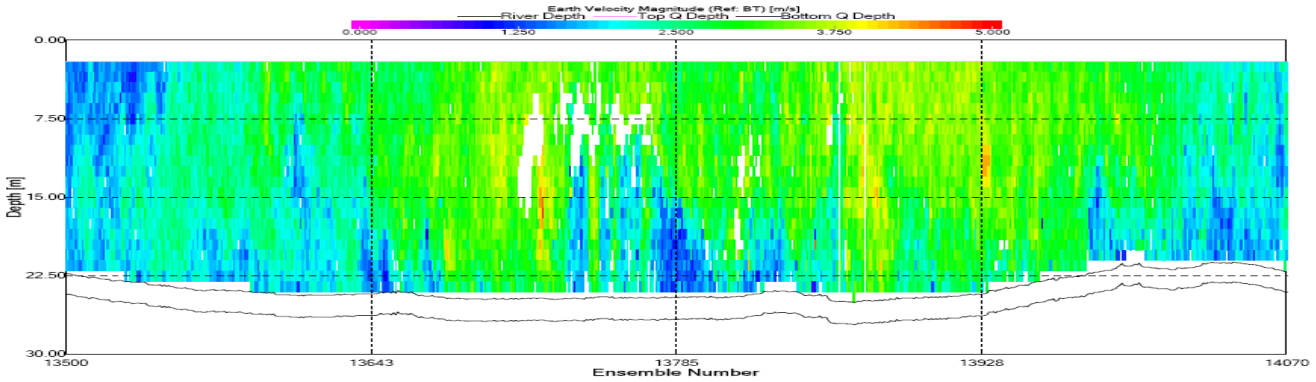
Turbulence Monitoring



- 50m downstream of pile
- Spring Tide, HW-3
- 10 minute transect across Lough
- Cross-arm + rotors submerged
- ADCP signal lost adjacent pile



- 150m downstream of pile
- Spring Tide, HW-3
- 10 minute transect across Lough
- Cross-arm + rotors submerged
- ADCP signal loss improving



- 250m downstream of pile
- Spring Tide, HW-3
- 10 minute transect across Lough
- Cross-arm + rotors submerged
- ADCP signal almost recovered

Enviromental Monitoring Status

- Incomplete
- 2 years since installation
  - Restrictive operation time due to MMO
  - Plant downtime
  - Weather windows/tide phasing
  - Survey team availability
- Completed in June 2010

ASSESSMENT OF PERFORMANCE FOR TIDAL ENERGY CONVERSION SYSTEMS

- **MRDF (DTi)**
  - MRDF University of Edinburgh 2007
- **BERR**
  - EMEC 2008

- **The protocols specifies two separate procedures as follows:**
  - Procedure to characterise the local resource, from a 30 day continuous record of tidal currents prior to installation of the machine.
  - Procedure to characterise the device performance envelope, from measurements of current velocity and power output over a 15 day period of device operation.

ASSESSMENT OF PERFORMANCE FOR TIDAL ENERGY CONVERSION SYSTEMS

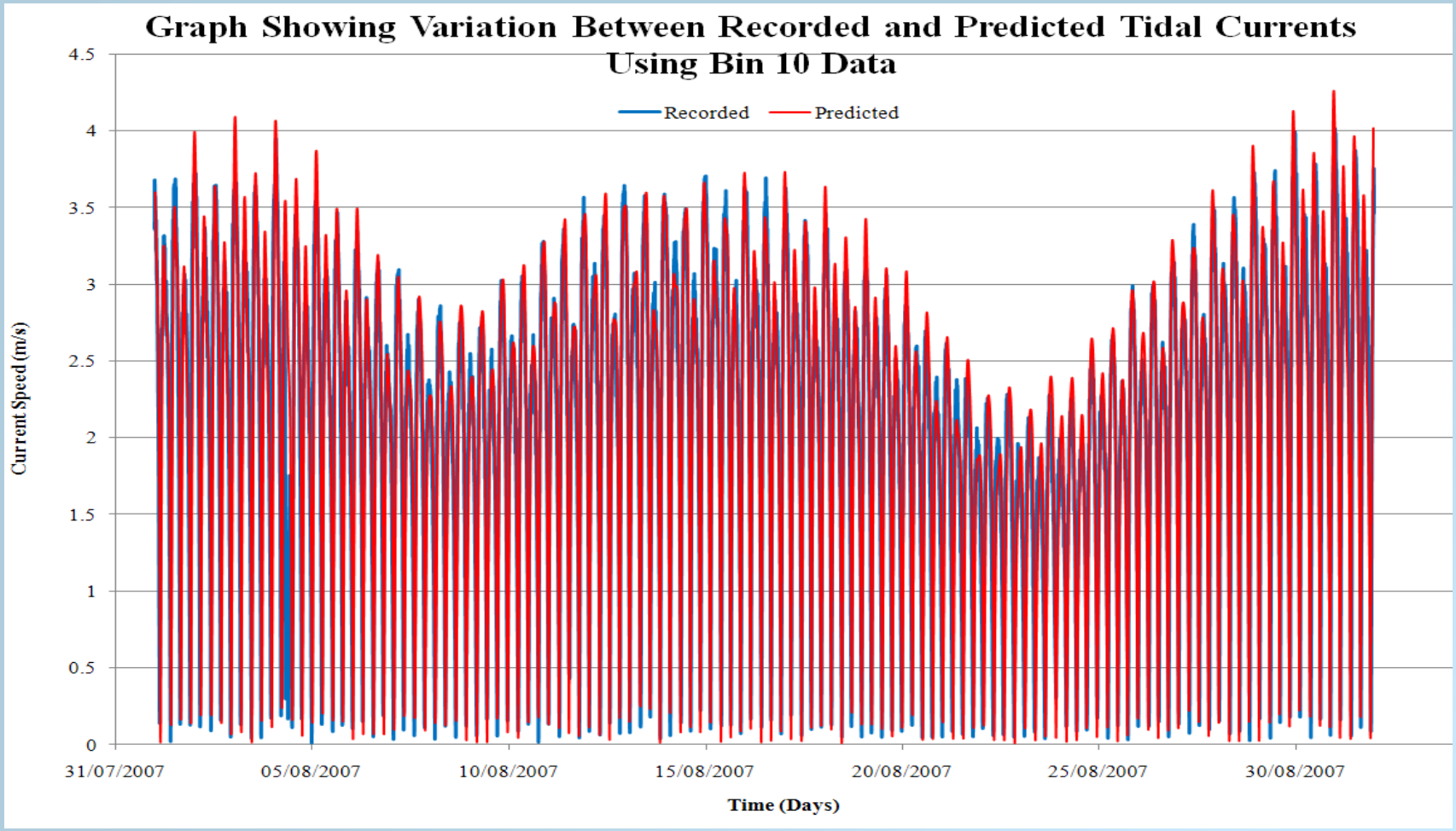
- **Accuracy**
  - ADCP accuracy <2% verifiable by calibration
  - Record velocities with resolution < 0.05m/s
  - Sample rate of 2Hz minimum
  - Ensemble averaging of 2 minutes or more
  - Direction accuracy of +/- 5 degrees
  - UTC time stamping
- **Resource Measurement/Analysis**
  - Minimum 10 min temporal resolution
  - ADCP location depth within 10% of TEC depth
  - Bottom-mounted
  - Maximum depth cell of 1m
  - Minimum 30 day monitoring period
  - Extract minimum of 20 tidal harmonic constituents
  - Calculate power flux of kinetic energy available to TEC

Harmonic Analysis

Harmonic Constants Determined from Harmonic Analysis of 2007 Data

Bin 10			Averaged Bins		
Constituent	**Amplitude (m)**	**Phase (°)**	**Constituent**	**Amplitude (m)**	**Phase (°)**
O1	0.084	322.94	**O1**	0.084	322.89
K1	0.131	155.14	**K1**	0.130	154.58
N2	0.351	154.62	**N2**	0.347	154.85
M2	3.194	256.80	**M2**	3.140	256.75
S2	0.500	353.10	**S2**	0.495	354.00
2N2	0.261	6.54	**2N2**	0.256	6.10
M4	0.180	169.01	**M4**	0.179	173.05
M6	0.345	250.81	**M6**	0.339	250.21
L2	0.141	271.53	**L2**	0.135	272.81
MS4	0.068	297.98	**MS4**	0.069	299.49
2MS6	0.199	21.47	**2MS6**	0.194	20.65
MN4	0.046	56.17	**MN4**	0.046	60.34
2MN6	0.091	156.50	**2MN6**	0.089	156.44
MNS2	0.046	228.37	**MNS2**	0.044	230.37
2MK3	0.049	199.62	**2MK3**	0.048	198.42
MK3	0.059	27.42	**MK3**	0.057	27.80
M8	0.055	178.54	**M8**	0.053	177.84
S4	0.004	258.95	**S4**	0.003	273.45
2SM2	0.054	309.38	**2SM2**	0.053	308.04
K2	0.268	118.05	**K2**	0.257	117.92

Harmonic Analysis



Kinetic Energy Flux

Comparison Between Predictions of Kinetic Energy Flux Using Bin 10 Data and Averaged Bins Data

	Energy Produced (MW hours)		Percentage of recorded data (%)	
	Bin10	Averaged bin data	Bin 10	Averaged bin data
Recorded data	2061.11	1952.91	100.00	100.00
19 Constituents	2039.17	1935.43	98.94	99.16
20 Constituents	2123.01	2012.60	103.00	103.06

Predicted Kinetic Energy Flux across the Performance Area of the Rotors for the Turbine's Deployment Lifespan

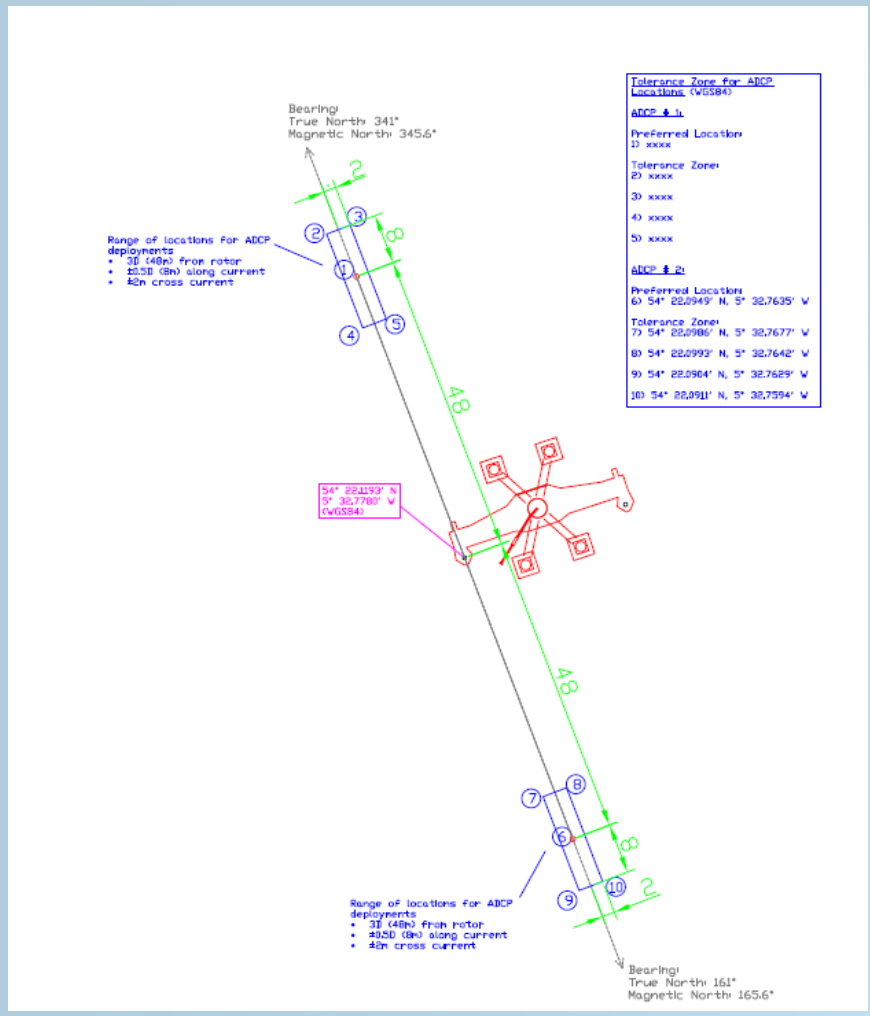
	Energy (MW hours)	
Year	**Bin 10**	**Averaged Bins**
2008 (April onwards)	19264.30	18265.64
2009	26450.03	25077.27
2010	27626.78	26200.18
2011	28157.06	26706.41
2012	28871.87	27385.88
2013 (Up to August)	17384.72	16497.33
Total:	147754.76	140132.71

ASSESSMENT OF PERFORMANCE FOR TIDAL ENERGY CONVERSION SYSTEMS

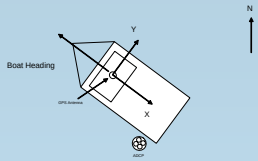
TEC Performance Certification

- ADCP positioned according to device geometry
- Typically upstream/downstream of capture area
- Sufficiently removed out of device influence
- ADCP depth within 10% of device depth
- 10 minute averaging
- Minimum 15 days data collection.
- Predefined data output format
  - TXT based
  - Excel, XML, Net CDF

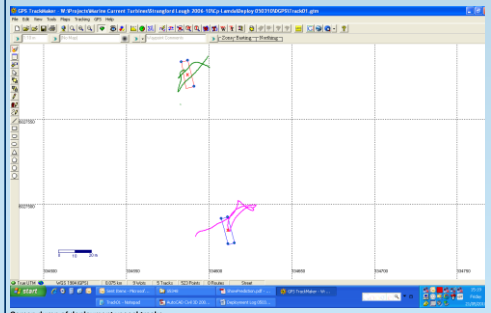
ADCP Deployment – Cp/Lamda



Deployment Information	
Date	05 March 2010
Time	03/05/2010,16:13:59,0
Latitude	54.3690748
Longitude	-5.5463028
Boat Heading	- (Magnetic/True North)
X	0.5m
Y	0m
Estimate of deployment rope angle to vertical	0 degrees
Recorded by	Cuan Boake



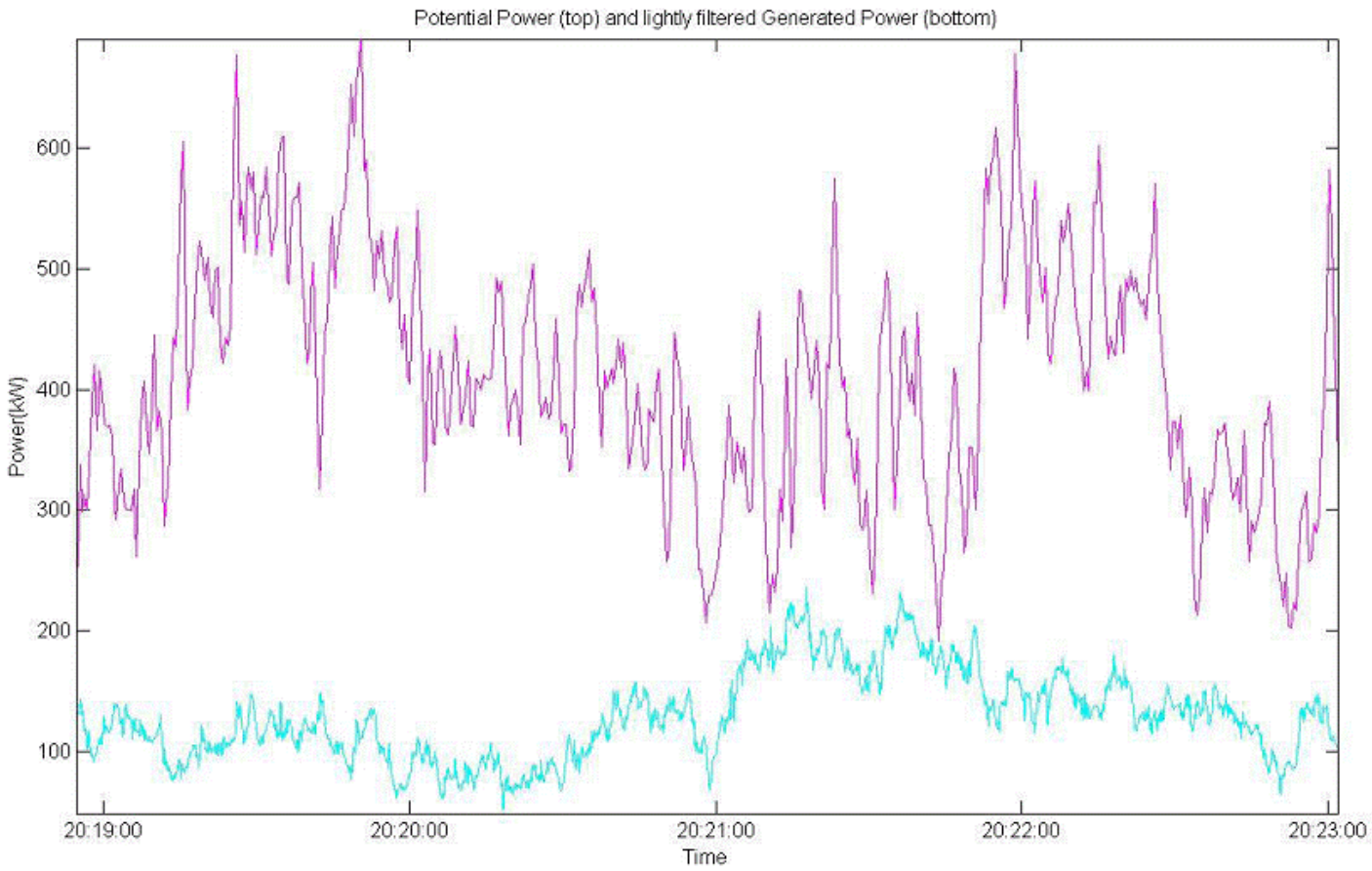
Other information (sea state, deployment problems,...):



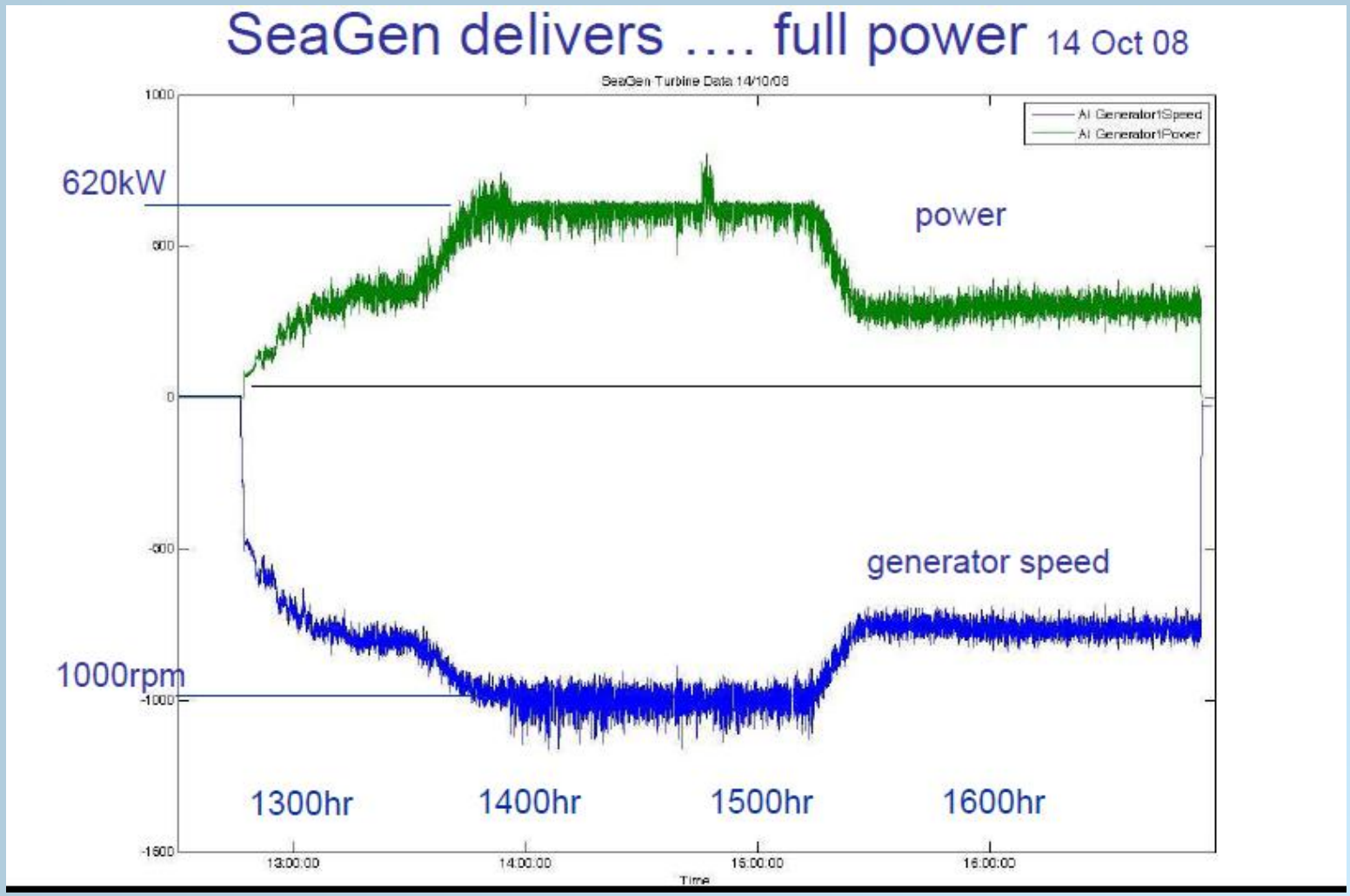
Screen dump of deployment vessel tracks.

- 15 minute slack tide
- Diver deployed
- Seagen current meter
- Bouy recovery

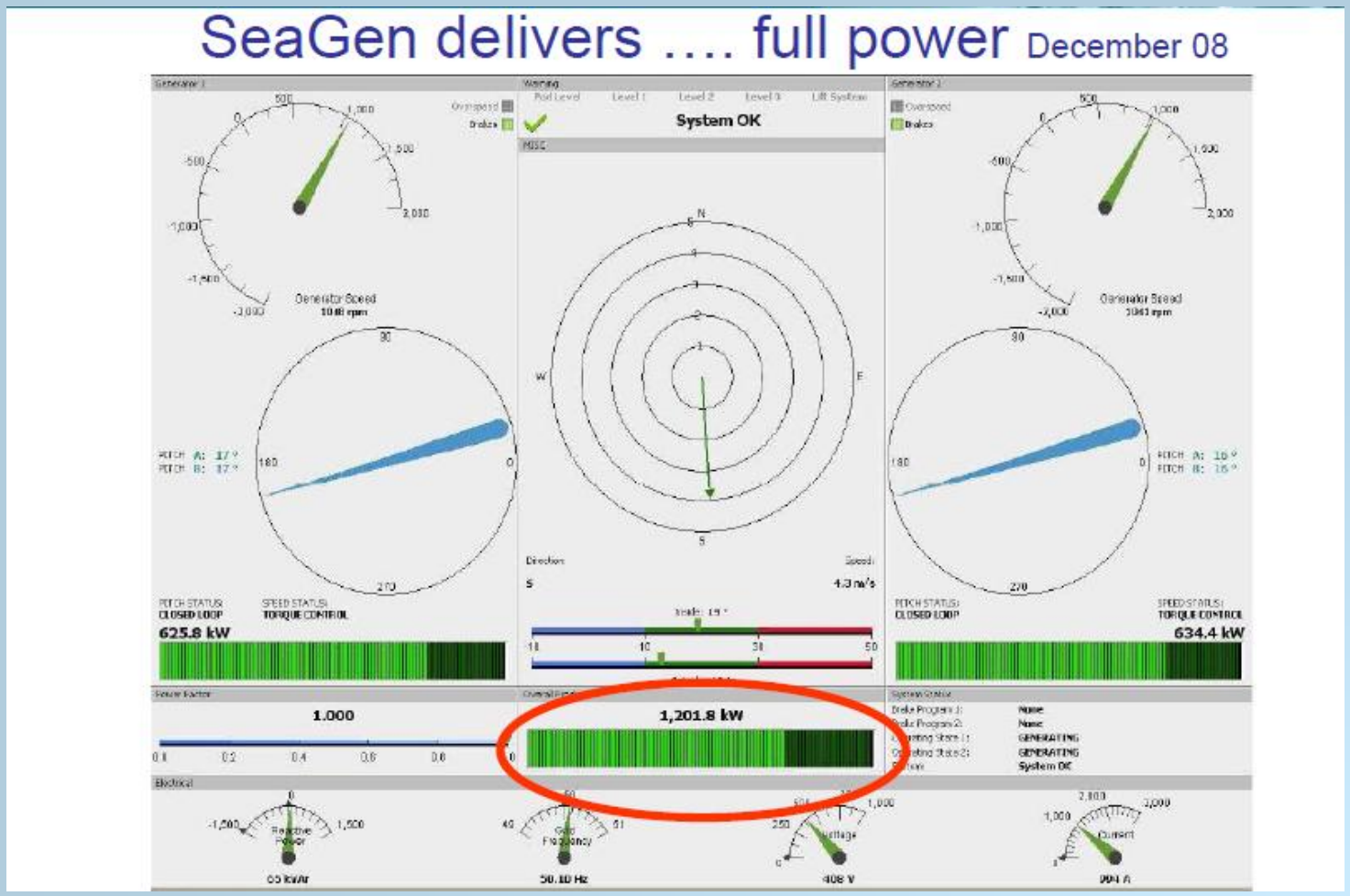
Seagen Performance Evaluation – Cp/Lamda Optimisation



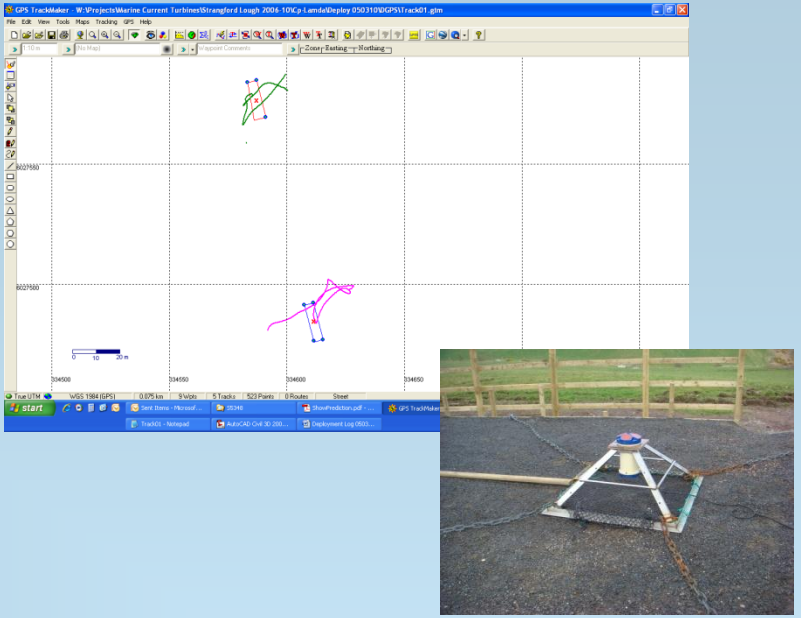
Seagen Power Production



Seagen Power Production



Power Certification



- 15 minute slack tide
- Diver deployed
- Seagen current meter
- Bouy recovery

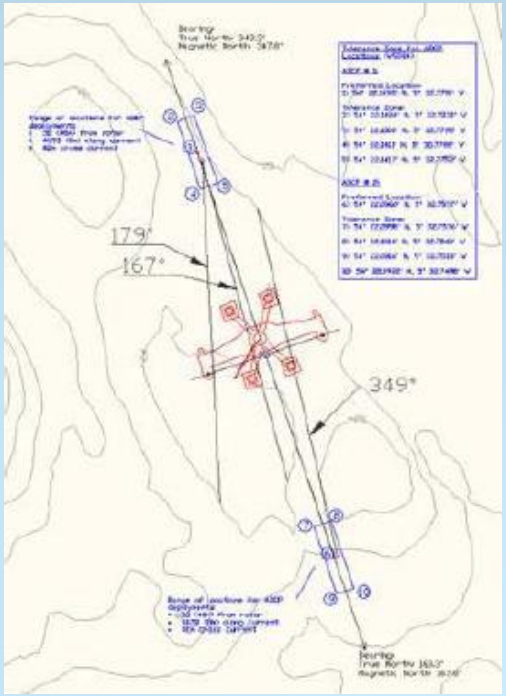
Direction Uncertainty

			Beam 3 Heading									
			Strangford Lough deployment		Land Based Calibration							
					Compass Rig away from ADCP	Compass Rig on ADCP Head		ADCP Internal Compass Reading				
Date	ADCP Serial No	Deployment Location	Diver Reading	Internal ADCP heading		Min	Max	Anchors Out	Anchors In	Anchors Off	USBL Off	ADCP Removed from Frame
23/04/2010	9527	N	212.5	202	212.5	212	213	215.34	215.17	214.96	214.89	212.34
23/04/2010	5348	S	70	70.2	72	71.5	72.5	65.75	65.75	65.02	65.05	62.5

Table 1: Compass Heading Results

ADCP Serial No	Deployment Location	Anchors	USBL	Frame
9527	N	0.38	-0.07	-2.55
5348	S	0.73	0.03	-2.55

Table 2: Equipment Compass Influence



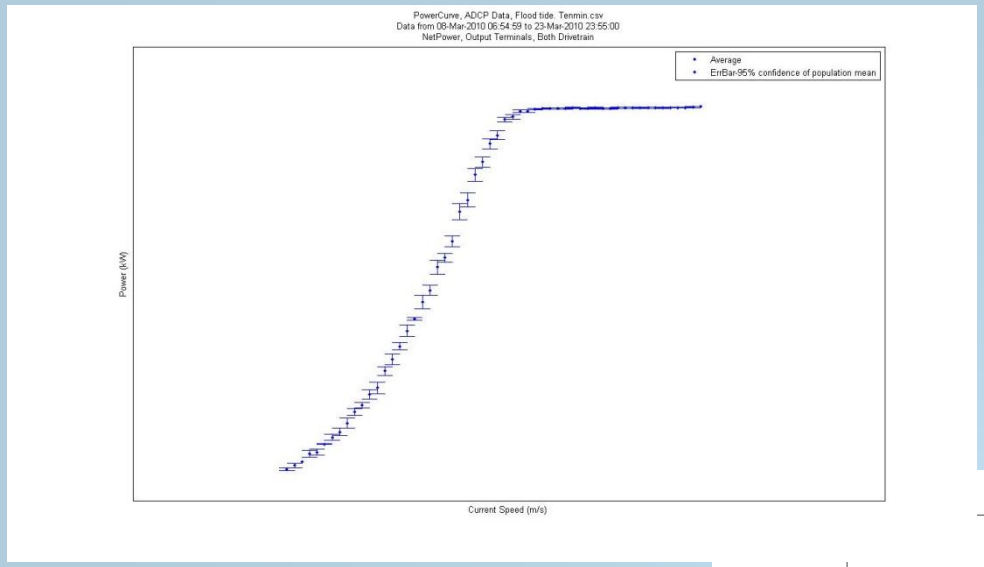
Data Analysis

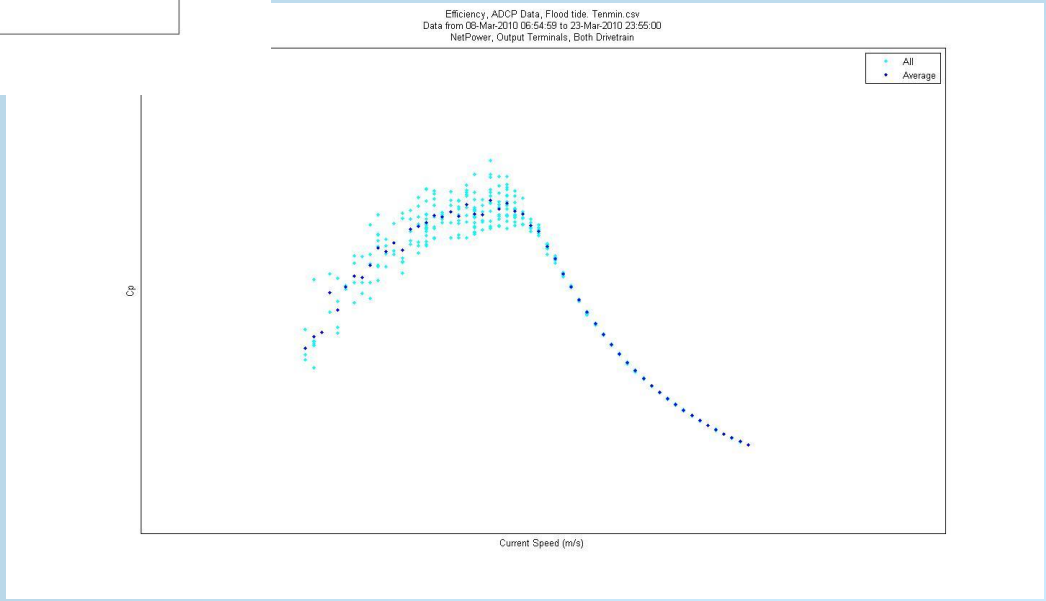
- 1Hz pings, 2s ensembles
- 2-10min averaging
- Time drift
- ADCP/Rotor relative height
  - Independant survey
  - Pressure calibration (zero!)
- Perpendicular (incident) flow - Cp
  - Magnitude used

Results

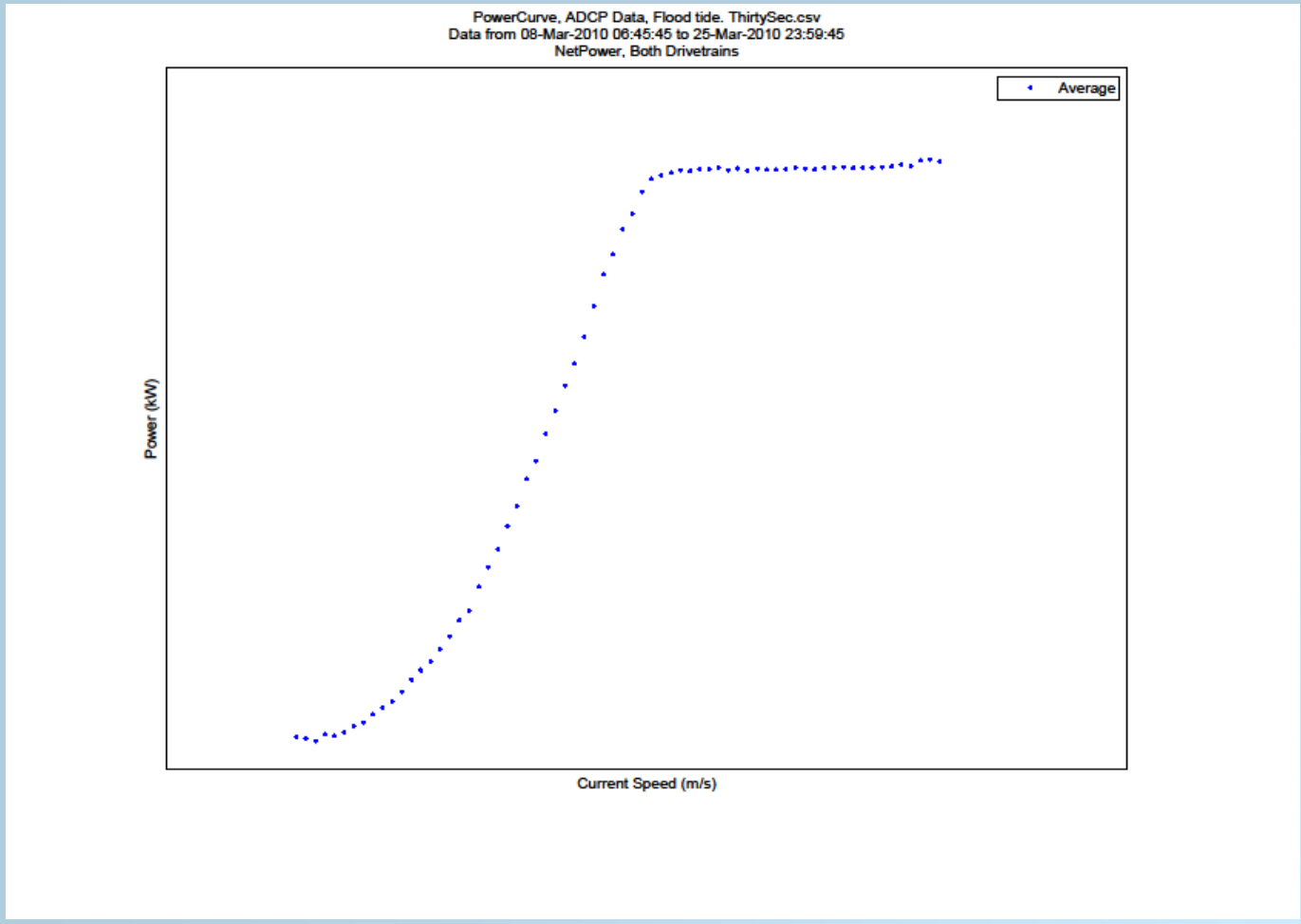
- 1200kW rated Power
- Peak average (Flood & Ebb tides) turbine efficiency (based on net power before turbine transformer) is 0.43
  - Using current magnitude
- Average Rotor efficiency of 0.48.
- Still to be verified by DNV

Results

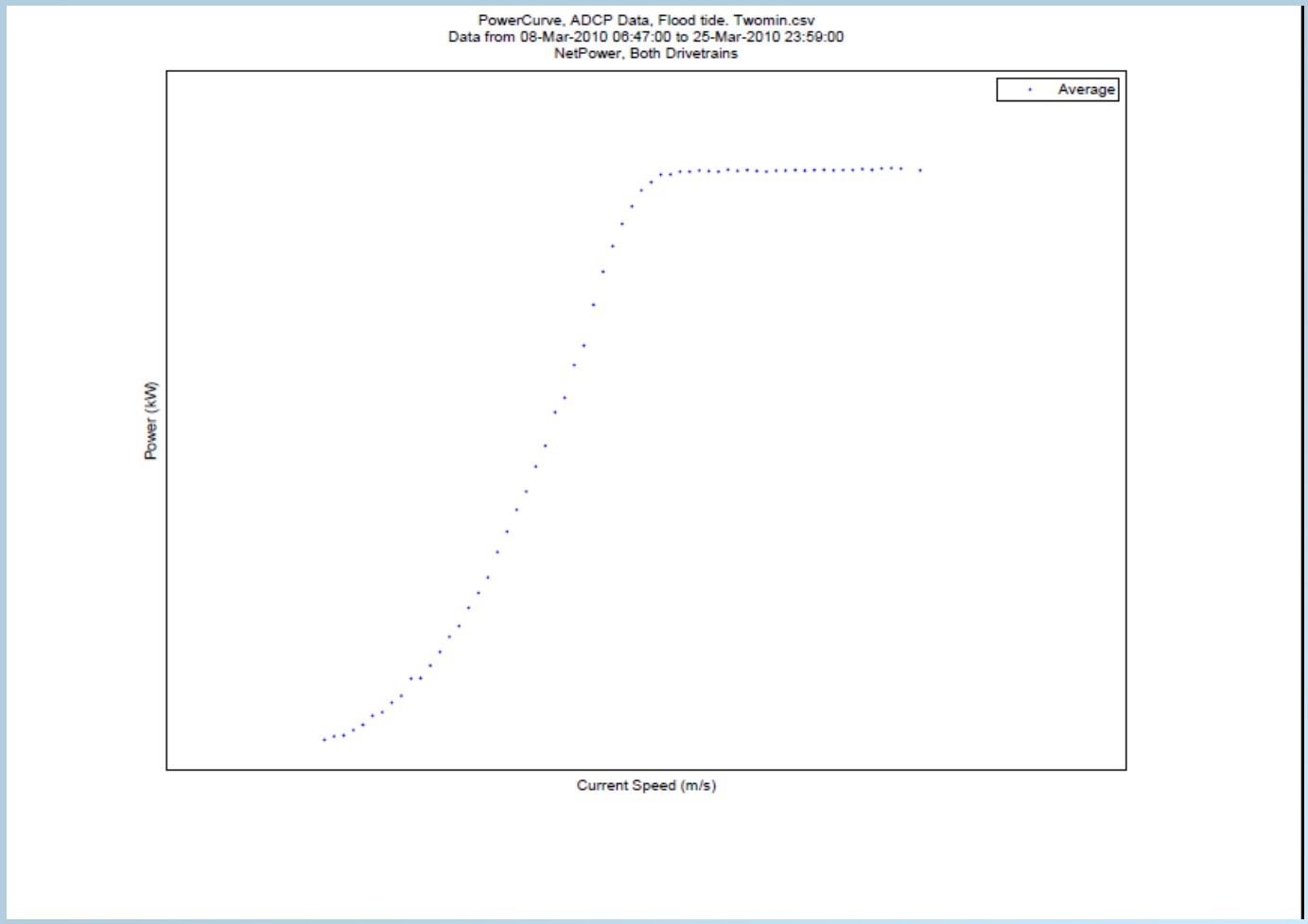

PowerCurve, ADCP Data, Flood tide. Tenmin.csv
Data from 08-Mar-2010 06:54:59 to 23-Mar-2010 23:55:00
NetPower, Output Terminals, Both Drivetrain
Average
ErrBar-95% confidence of population mean
Power (kW)
Current Speed (m/s)


Efficiency, ADCP Data, Flood tide. Tenmin.csv
Data from 08-Mar-2010 06:54:59 to 23-Mar-2010 23:55:00
NetPower, Output Terminals, Both Drivetrain
All
Average
Cp
Current Speed (m/s)

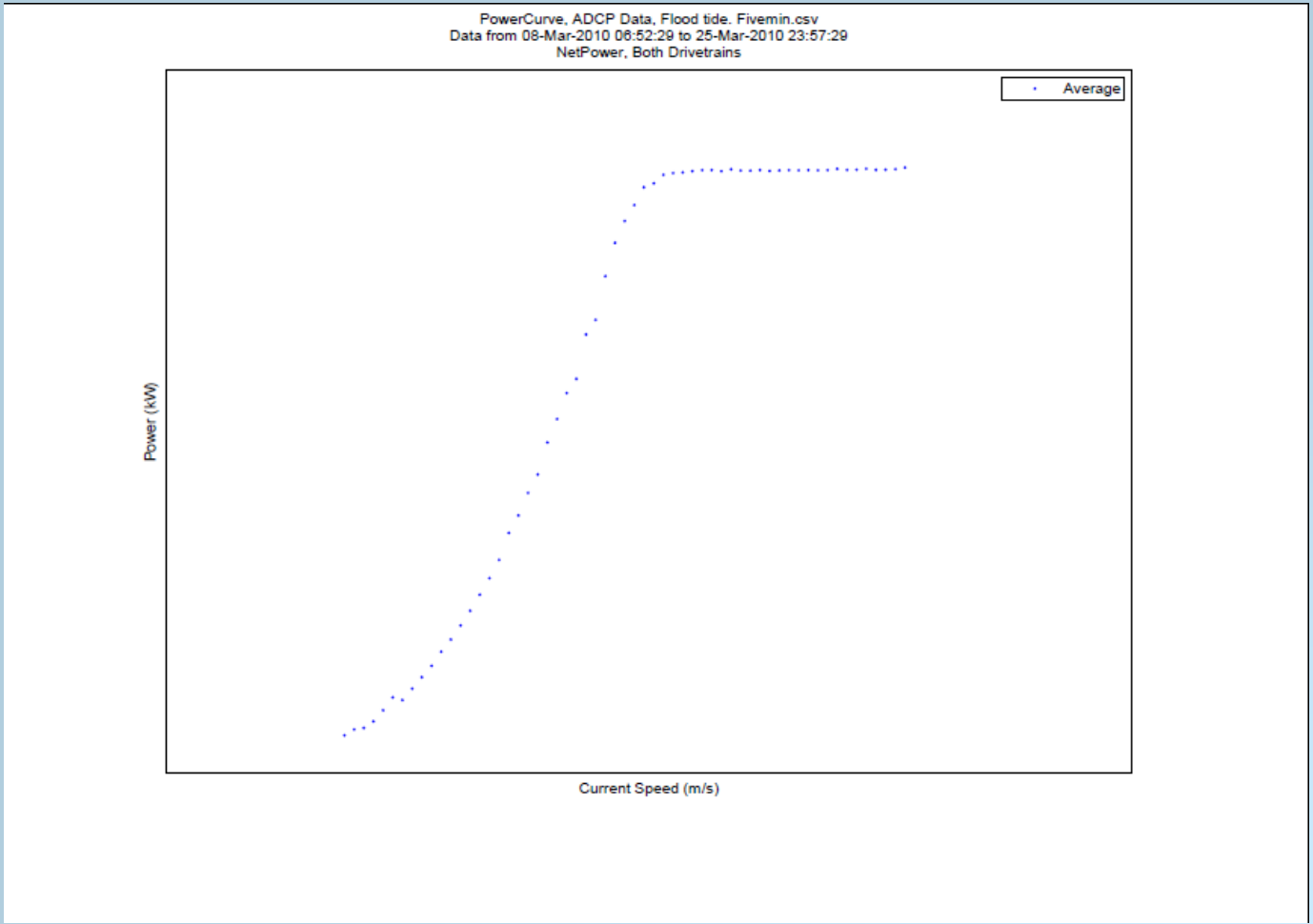
Averaging Comparison



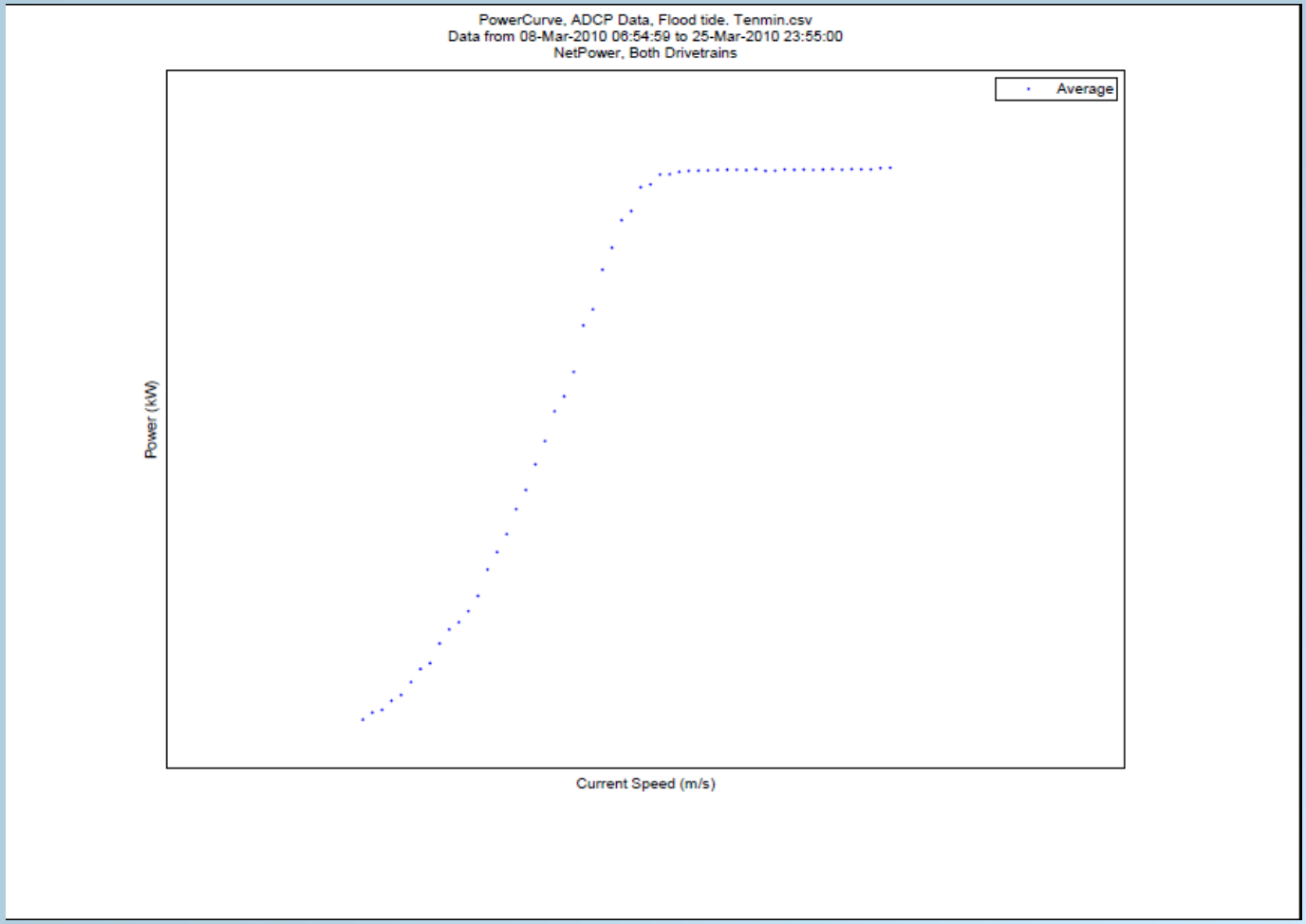
Averaging Comparison



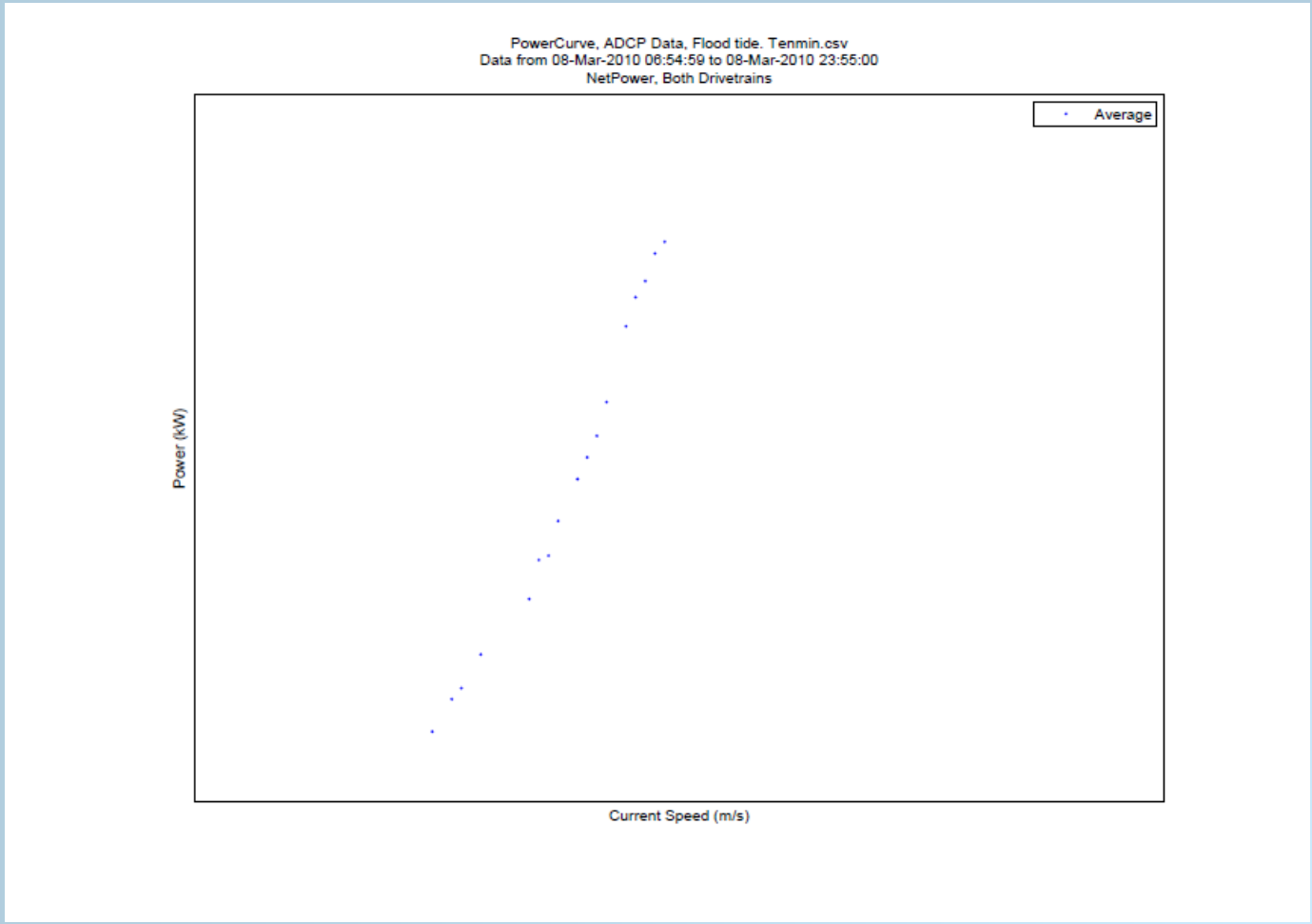
Averaging Comparison



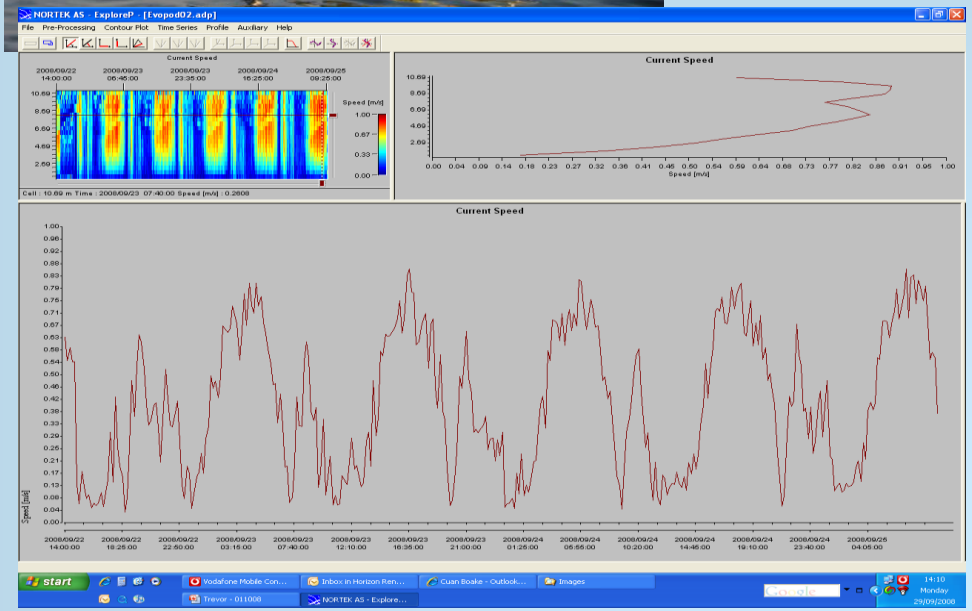
Averaging Comparison



Convergance of Power Curve



1/10th scale tidal machine - Evopod



10th Scale Steady State Testing

- 16 x 6m^2 catamaran hull
- AWAC/DGPS for velocity
- VMSurvey Software
- 1 Vector (need more!)
- 64Hz sampling, 170s run
- Phase-space filtering (Cea, Goring)

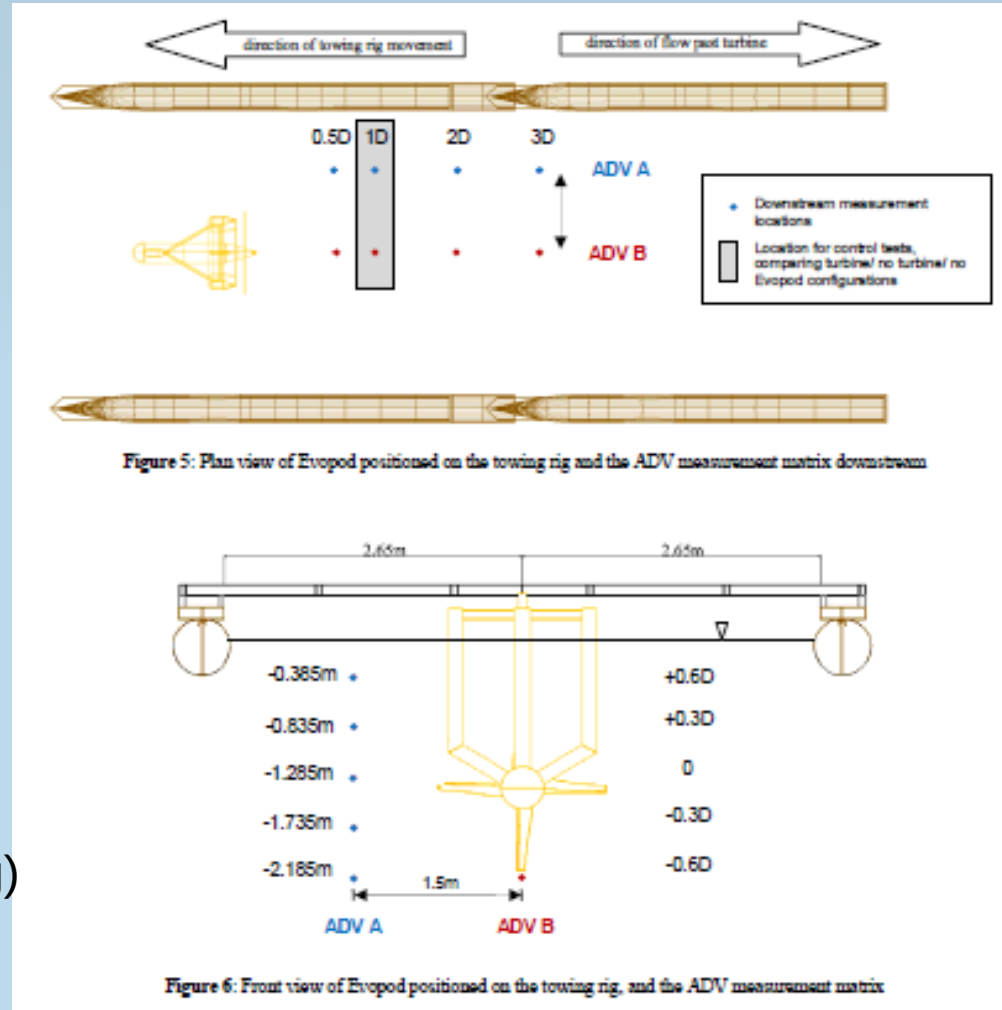


Figure 5: Plan view of Evopod positioned on the towing rig and the ADV measurement matrix downstream

Figure 6: Front view of Evopod positioned on the towing rig, and the ADV measurement matrix

10th Scale Steady State Testing

$$u_{deficit} = 1 - \frac{u_w}{u_0}$$

Non-dimensional velocity deficit

$$I \cong \frac{\sigma}{\overline{U}}$$

Turbulence Intensity

Results

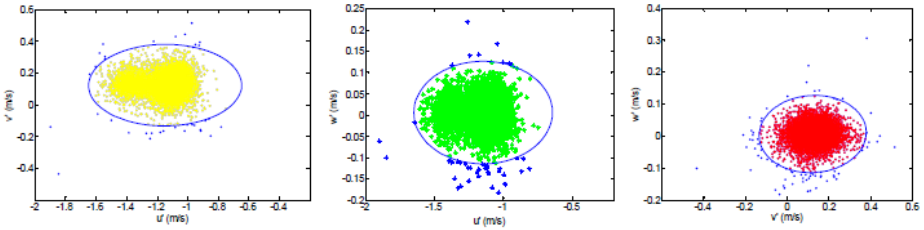
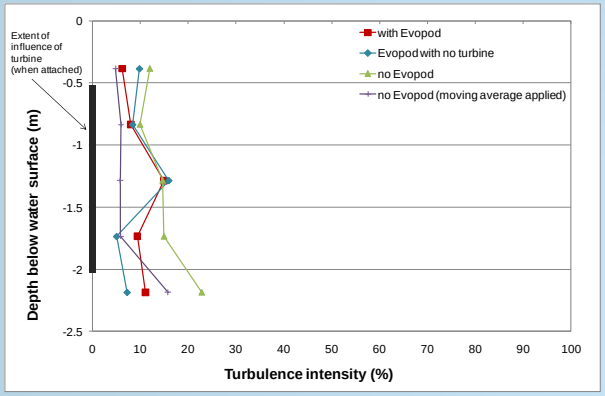
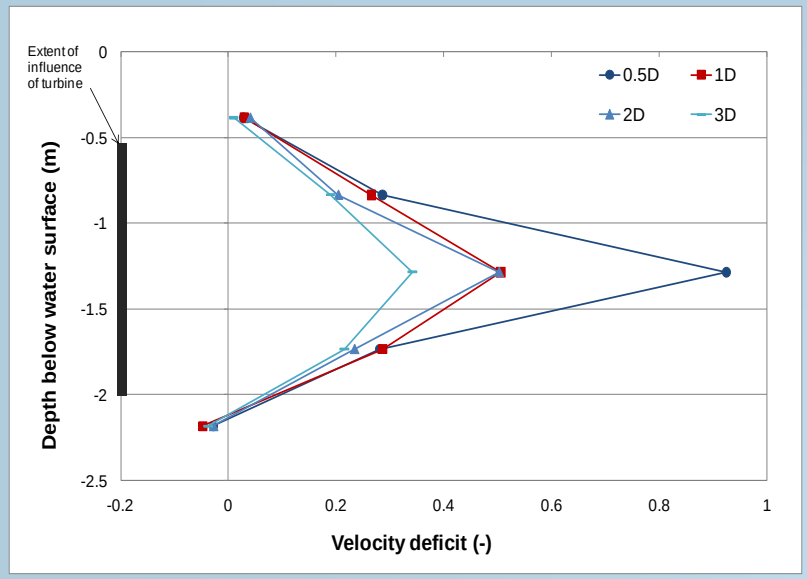


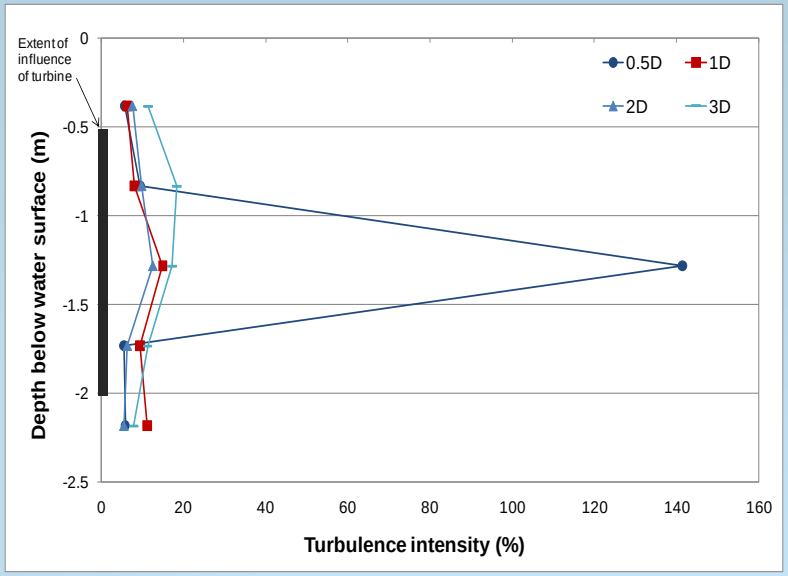
Figure 7: Raw velocity data, for one run, plotted in the velocity correlation space, u'-v', u'-w' and v'-w'



Results



Velocity deficit downstream of Evopod with its turbine attached (along centreline, ADV B)



Turbulence intensity downstream of Evopod with its turbine attached (along centreline, ADV B)

Areas for Future Investigation

1. Develop vessel-mounted turbulence measurement methodology
2. Develop turbulence measurement algorithms
3. Develop instrumentation to suit tidal industry
    1. Direction accuracy for certification
    2. 2D matrices
    3. 3D matrices would be nice

The End