Tidal Stream & Wave Energy

Climate Change and Energy: A Marine Perspective
Marine Symposium, Liverpool
25th Jan 2010

Tim Stallard

JOULE Centre, School of Mechanical, Aerospace and Civil Engineering
University of Manchester

An overview of Tidal Stream & Wave Technologies and ongoing R&D.

- Tidal Stream
  - State of development
  - Present research & development activities
- Wave Energy
  - State of development
  - Array-devices (Manchester Bobber)
  - Arrays of devices
- Summary

UK Tidal Stream Resource

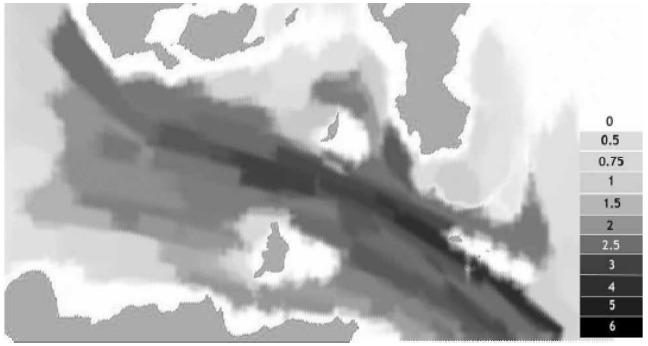
Extractable resource ~ 16TWh/yr (Carbon Trust, 2006)

- Potentially 4.5GW installed capacity but at small number of sites

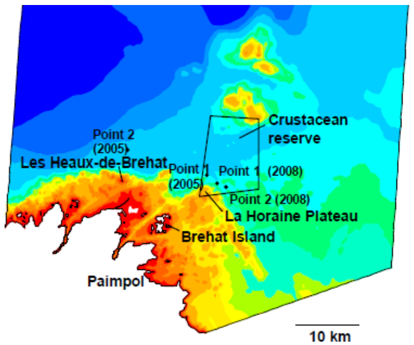
Of this: ~ 50 % at flow speeds of 2.5 to 4.5 m/s

> 60 % in water depths > 40 m

- Channels: Pentland Firth, EMEC, Alderney
- Headlands: Anglesey, Paimpol-Brehat, Portland
- Estuaries: Strangford, Bay of Fundy, Severn…



Pentland Firth, Owen et al. 2007



Paimpol-Brehat, Martin et al 2009

Strangford, Boake 2008

Tidal Stream Devices

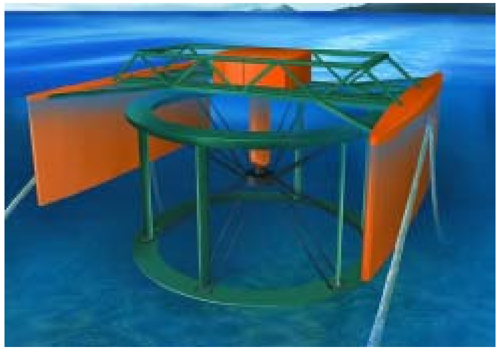
Variety of devices at lab- and intermediate scale

SMD TiDEL

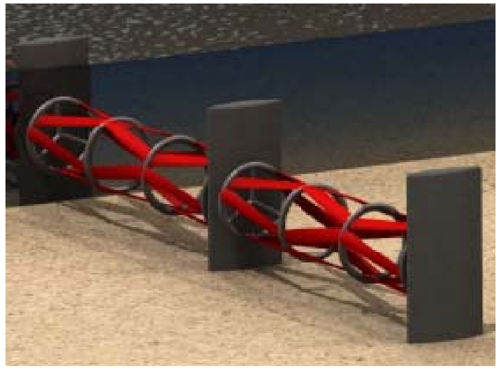
OpenHydro

MCT SeaFlow

Verdant Power

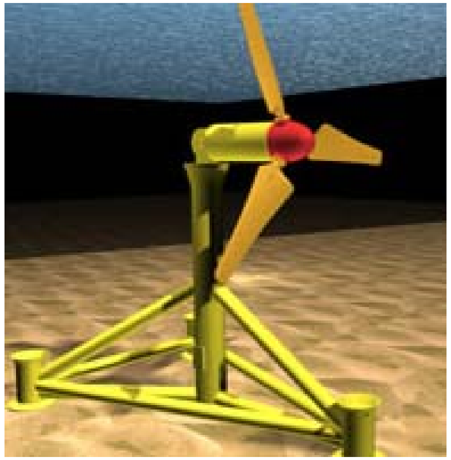


Edinburgh Designs



University of Oxford

Horizontal Axis



Marine Current Turbines,

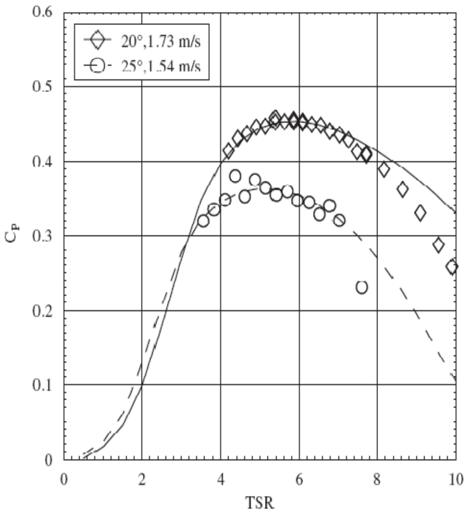
1.2 MW Strangford Loch (2008)

1.2 MW Bay of Fundy (2011)

10 MW Anglesey (RWE npower, 20??)

Tidal Generation Limited, TGL

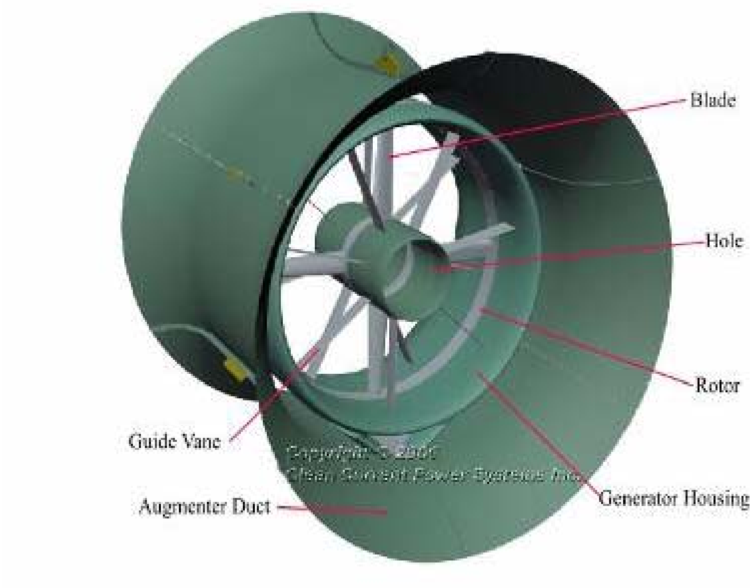
500 kW EMEC (2010 / 2011)



Turbines typically -

- Diameter ~ 16-20 m operating at tip speed ratio ~ 4-7
- Support structure & control methods vary

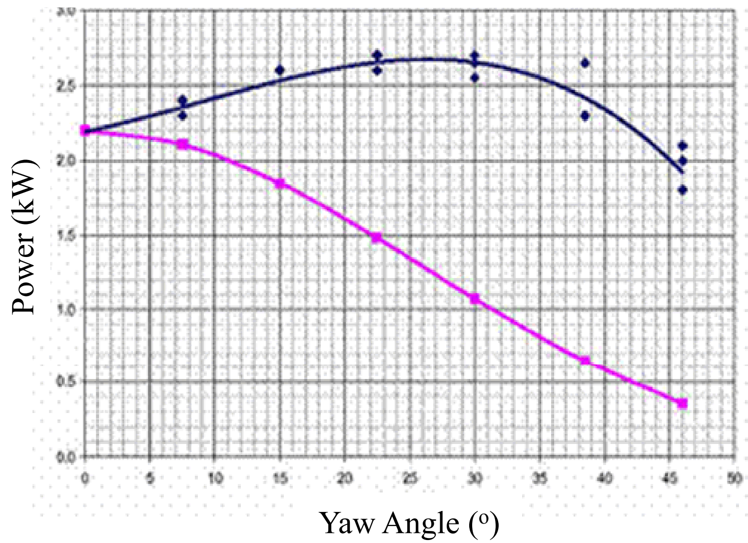
Open Centre

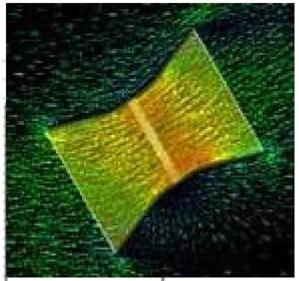


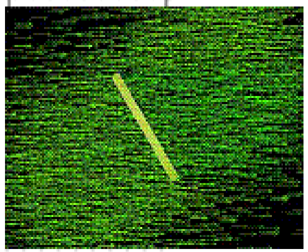
Cleancurrent
17 m diameter rotor
Bi-directional, Direct drive
¼ scale at Race Rocks, BC. 2004
Full Scale at Bay of Fundy, 2010

OpenHYDRO
18 m diameter rotor,
Bi-directional, Direct drive
Custom barge for rapid deployment
$^{1}/_{3}$ scale at EMEC, UK. 2006
4 x 0.5 MW at Paimpol-Brehat, 2010 (EdF)

Ducted: Lunar Energy







16 m diameter rotor,
Venturi flume - accelerates flow
- allows operation up to 40°
"Cassette" power take-off

www.lunarenergy.co.uk

Present R&D Issues

- Turbulent loading –
  - EPRI (2006), Carbon Trust (2005), DTI MRDF Protocols (2006)
  - Characteristics of ambient tidal turbulence – **data needed**
  - Impact of turbulence on performance, loading and wake
- Farm configuration & performance –
  - Impact of wake recovery & turbulence on downstream devices
  - Impact of energy extraction on incident flow
- Deployment methods –
  - Offshore work in strong tidal flows is not trivial!

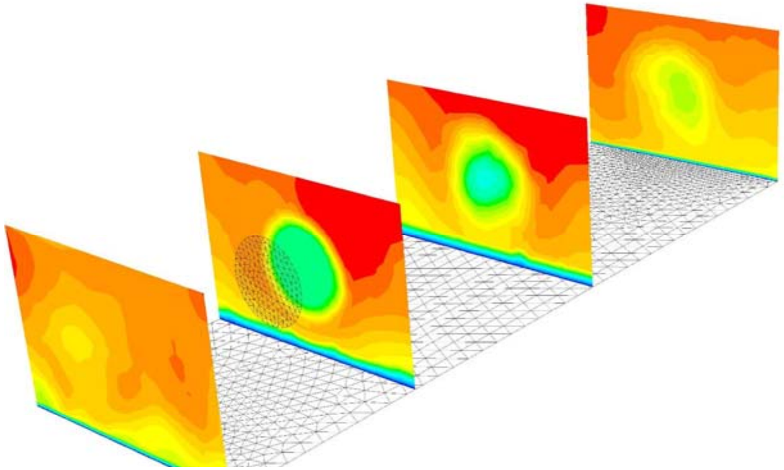
Unsteady loading

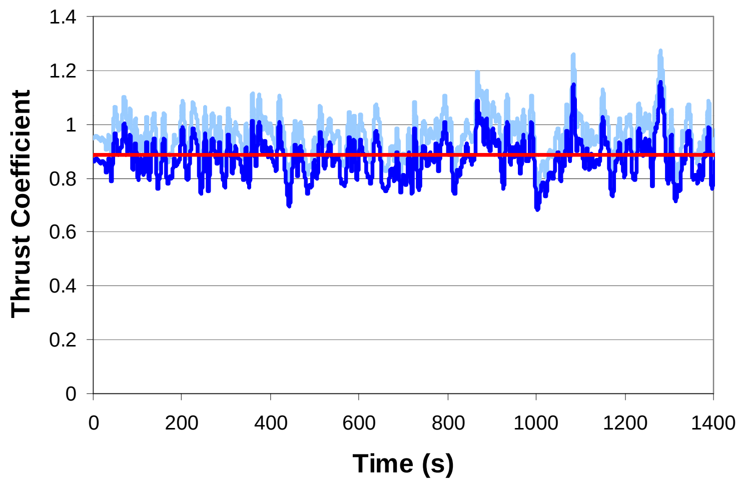
CFD studies 2007-08

- Large-scale turbulent inflow modelled by Synthetic Eddy Method.
- Device modelled as porous disc

- Shorter wakes in turbulent flow
- Horizontal load variation > ±20%

- Ongoing collaboration with EdF
  – Resolve free surface
  – Resolve rotating machine





Gant & Stallard, ISOPE08

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PerAWAT

Tidal Stream Group: **Universities of Oxford, Edinburgh and Manchester, EdF, Garrad Hassan & EoN**

Wave Energy Group: University of Oxford, Queens University Belfast, EdF

Device / Farm Scale: Effect of free surface, spacing & turbulence on performance

To establish & validate numerical models to predict the hydroydnamic performance of arrays of wave and tidal energy converters

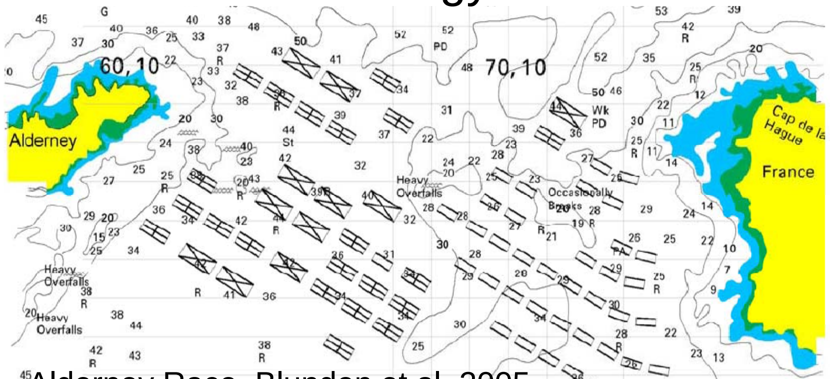
Models -
- RANS (Oxford),
- Code-Saturne LES (Edinburgh),
- Engineering tool: TidalBladed (GH).

Experiments –
- ~ 1:10th (Edinburgh)
- ~ 1:30th (EdF)
- ~ 1:70th (Manchester)

Site Scale: Modification of flow and performance due to energy extraction

Models –
- Telemac 2D & 3D (EdF),
- OXTIDE (Oxford),
- Engineering tool: TideFarmer (GH).

Experiments at coastal scale (GH)



Alderney Race, Blunden et al. 2005

UK Wave Resource

- Locations:

  Offshore: >20km to shoreline, > 50 m depth

  Nearshore: <20 km, 20 - 40 m depth

  Shoreline

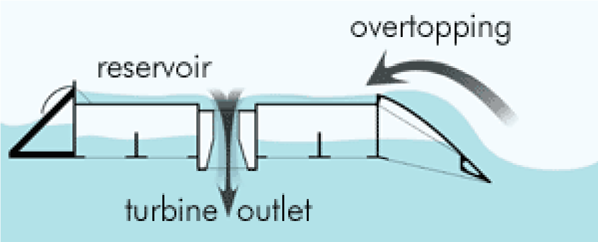
- Theoretical resource
  - 600-700 TWh / yr: Offshore
  - 100-140 TWh / yr: Nearshore

- Practical resource
  - 50 TWh / yr: Offshore
  - 7.8 TWh / yr: Nearshore
  - 0.2 TWh / yr: Onshore

~ 19 GW installed capacity (capacity factor of 0.3)

Wave Devices

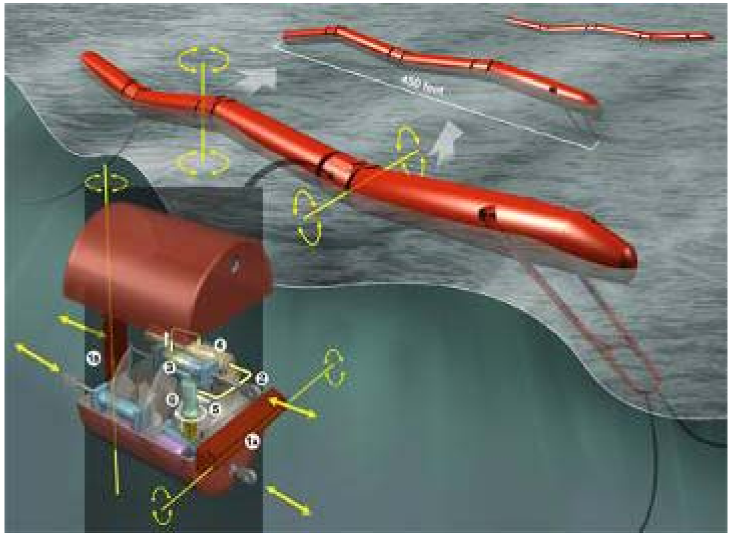
- Multiple device types
  - Overtopping
  - Oscillating float: Point absorber
  - Oscillating water column
  - Attenuator: Pelamis, Anaconda
  - Structure supported, closely spaced array



Wavedragon, 4MW

AWS, 2.4 MW

OPT, 150 – 500 kW



Pelamis:

~ 30 yrs development
- 750 kW prototype: EMEC 2004
- 3 x 750 kW prototype: at Portugal 2007 – 2009

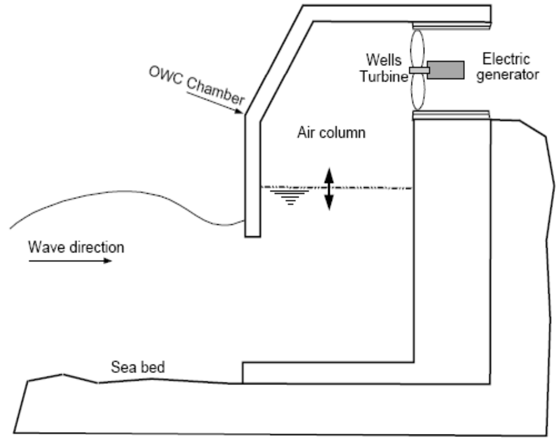
- 750 kW prototype2: EMEC 2010
- 4 x 750 kW p2: EMEC *20??* (eON)
- 25 x 750 kW p2: Shetland *20??*

Oscillating Water Column

Working surface is air / water interface

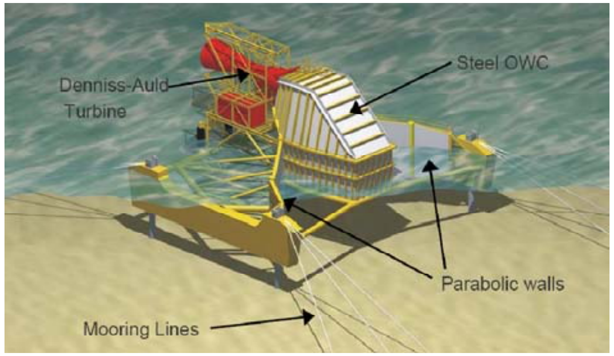
Extremes less severe due to location

Bi-directional turbines: Wells / Impulse



LIMPET, Islay.
PICO, Azores: 1990's

ENERGETECH
Parabolic Walls to amplify height



www.energetech.au, 2003

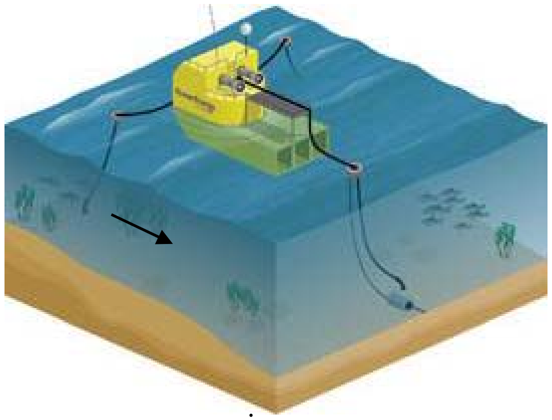
VOITH - WAVEGEN
OWC Breakwaters:

Mutriku Breakwater
16 x 20 kW turbines

Siadar, Isle of Lewis
4MW, 200 m breakwater

Floating OWC

Ocean Energy Buoy –
Air turbine, ~ 25 m beam, rated at 2 MW full-scale


www.oceanenergy.ie

¼ scale offshore trials 2006

www.orecon.com

ORECON -
Rated at 1.5 MW, Diameter 30 m
Tension moorings similar to Oil & Gas
Three water column chambers
  - different lengths to extend operating range

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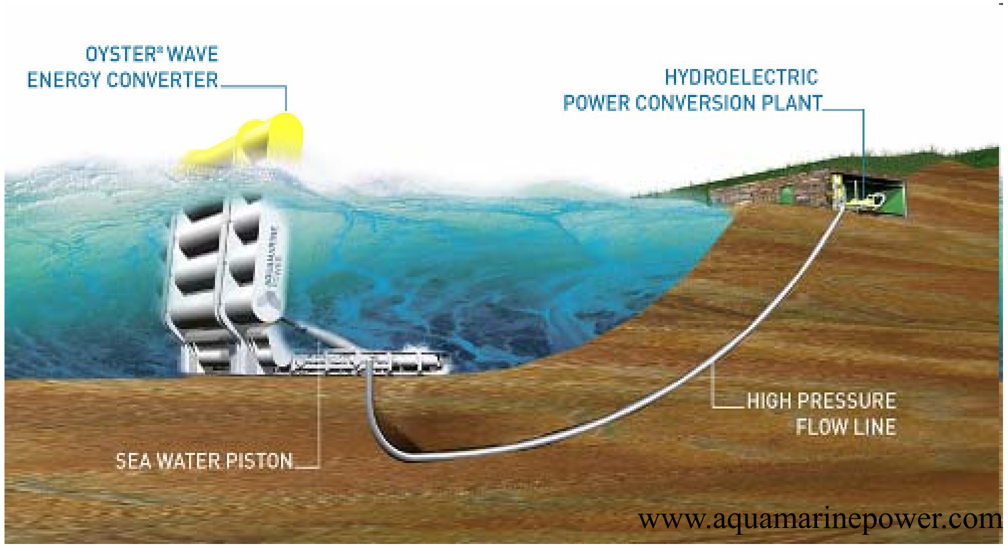
Nearshore: OYSTER

Bed mounted device located in nearshore (~10 m depth)
Oscillates in pitch – nearly surge & sheds high load
Oscillations pump water to shoreline generator
Generator rating per device: 600 kW

EMEC deployment 2009



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Array WECs

Multiple generating units supported on single structure

- Capture element close to free surface
- Higher rated power per ‘unit’: ease of maintenance
- Theory suggests power enhancement due to interactions
- Typically 8 – 10 m diameter floats

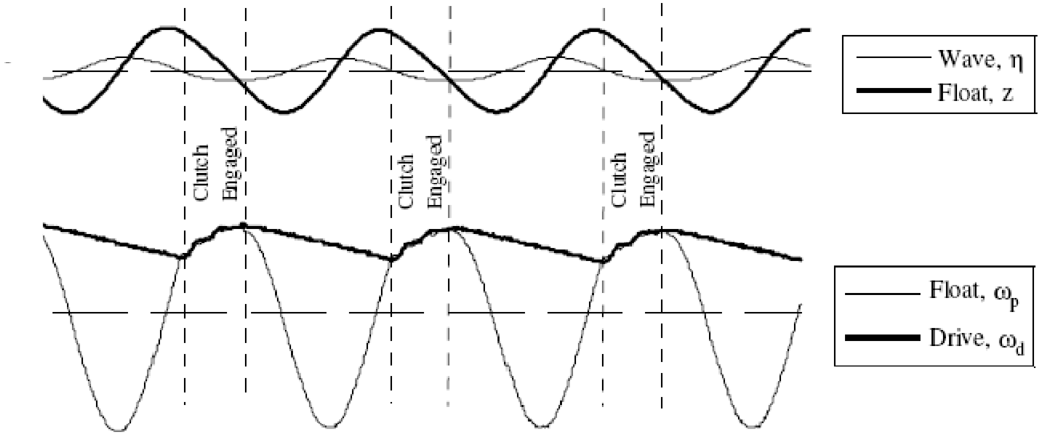
Fred Olsen Buldra, 1:3 trials, 2005

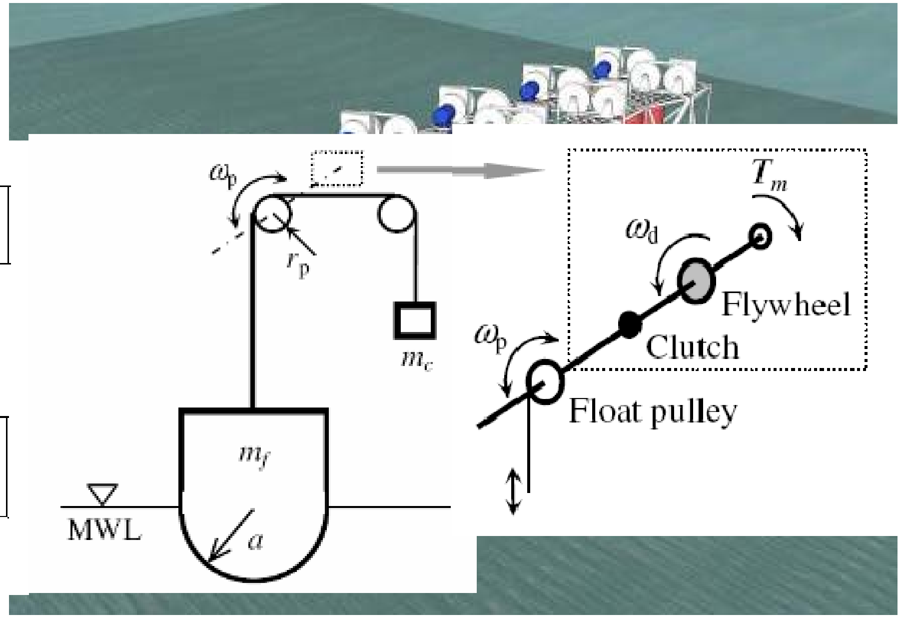
Trident Energy, NAREC, 2005

WaveStar, 2005

Manchester Bobber

- **Array of floats** extract energy from near wave surface
- High power density: 5MW rated in ~100m x 40m
- **Float shape** designed for operation in H_s up to 8 m
- **Tuning** of individual floats to enhance array output
- Modest horizontal loads on structure
- Standard components & structure





Development Team

- University of Manchester Intellectual Property Ltd (UMIP)
  - Dr. Frank Allison (Business manager)
- University of Manchester
  - Prof. Peter Stansby, FREng
  - Dr. Alan Williamson & Dr. Tim Stallard
- Industrial Partners
  - Royal Haskoning (EIA)
  - Renold Gear (drive train)
  - Renold Chain (chain drive)
  - ABB (electrical systems)
  - ODE (P-M & structure design)
  - Red Rooster (float interconnect)
  - Burntisland Fabrication (structure fabrication)

Background: 1:100th scale

1/100th scale tank testing 2004 - 2005

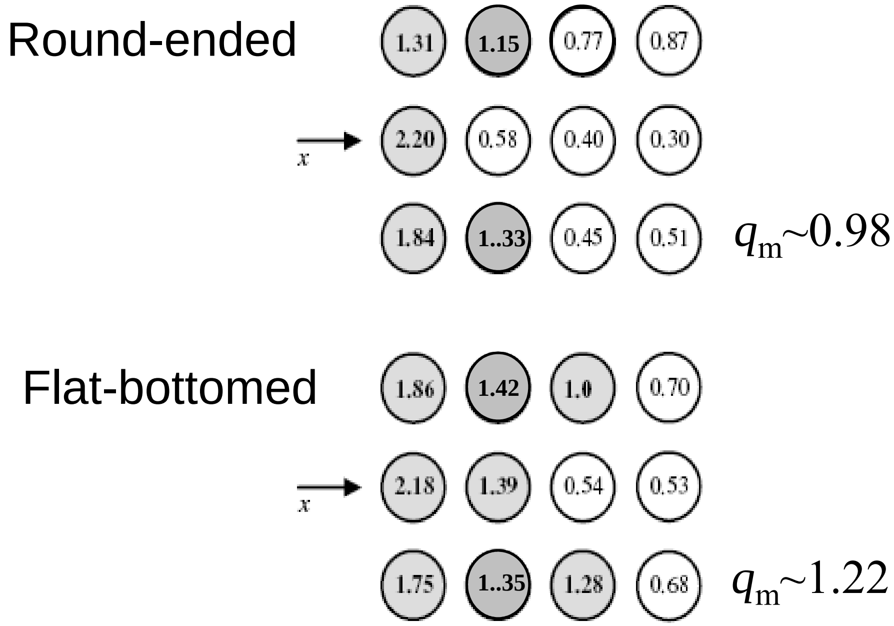
Background, 1:10th Scale

1/10th scale tank testing 2005 – 2006, NaREC.

Recent Developments, 1:70th Scale

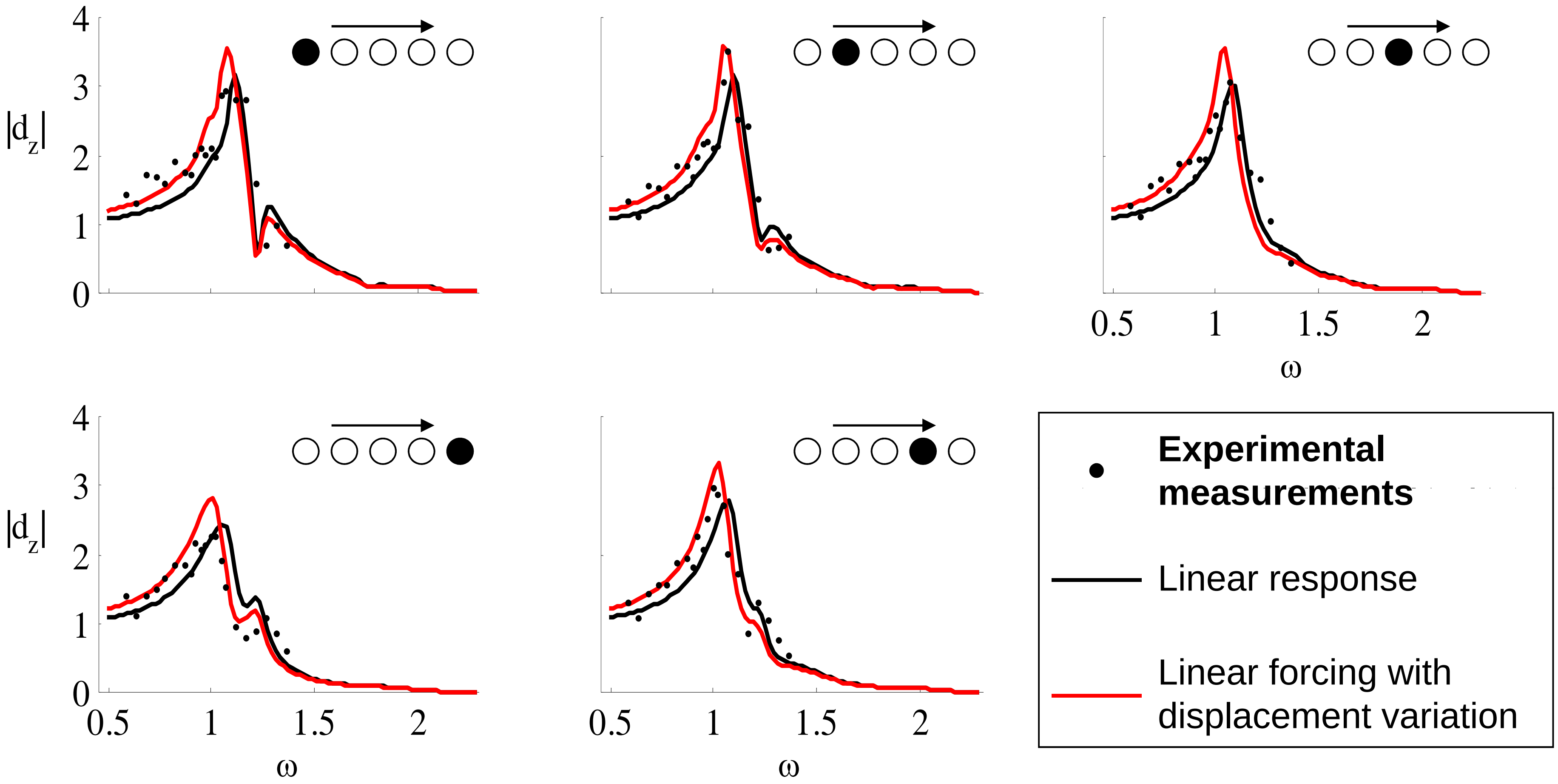
- 1/70th Scale Array Experiments & Device Modelling
  - Array interactions by Experiment & Model,
  - Wave climate modification, Extreme wave response, Float design

5 x 5 Array Interaction Experiments



Interactions at T = 10 s, Stallard et al. ISOPE08

Interaction Models

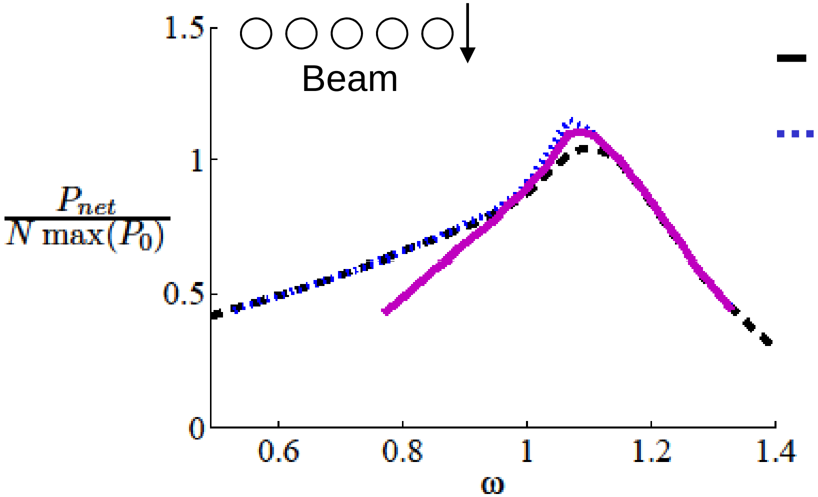


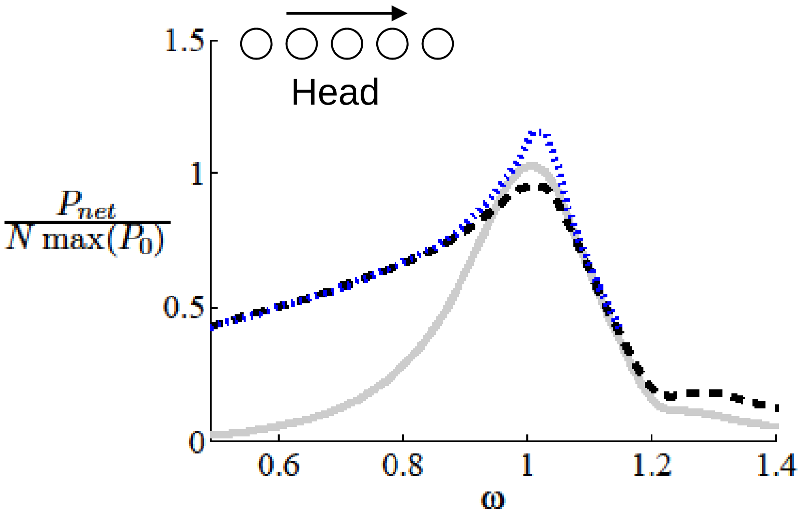
Thomas, Weller & Stallard, ICOE 2008

Array Optimisation (linear)

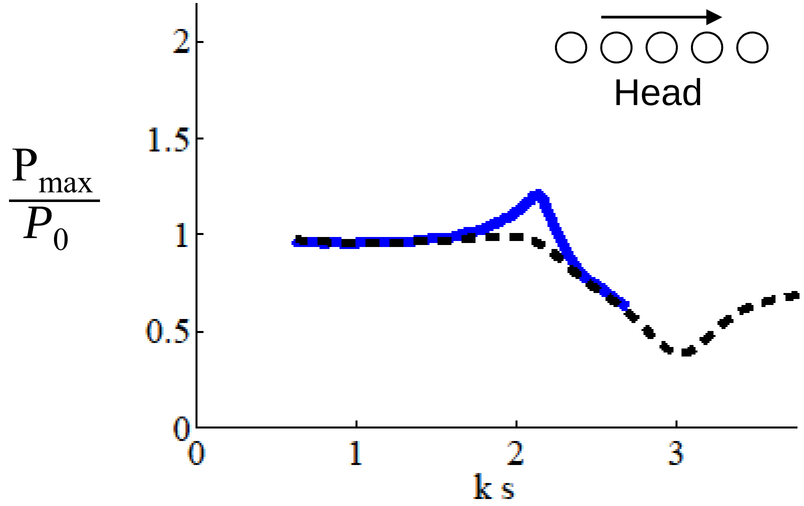
- - - Identical floats

········ Different floats





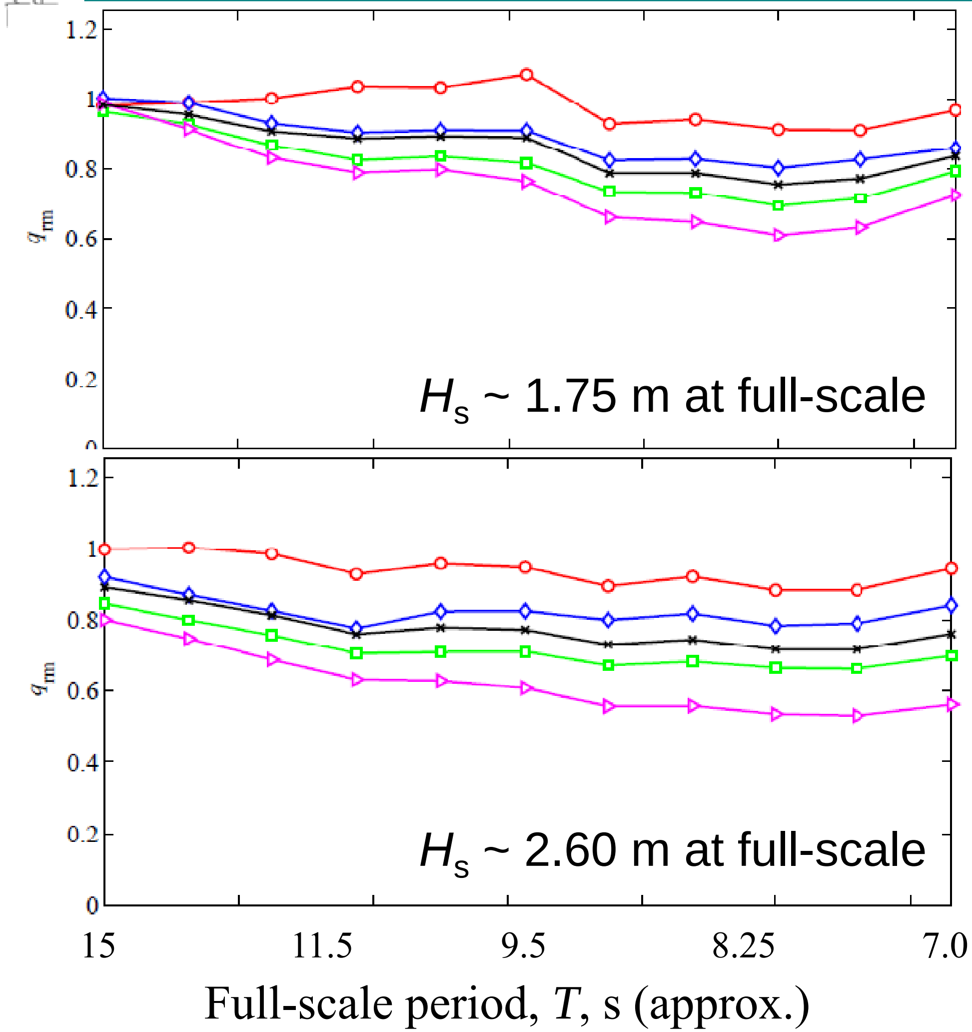
Maximum at each frequency



Peak interaction factor due to mass & damping modification

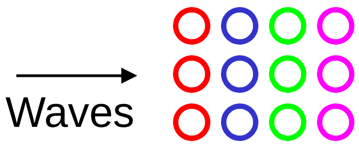
Bellew, S., Stallard, T. and Stansby, P.K.
EWTEC 2009

Irregular Wave Interactions

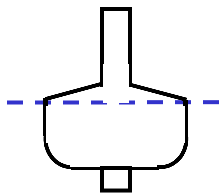


Identical devices -
Attenuation of output with row No.

3 x 4 ARRAY

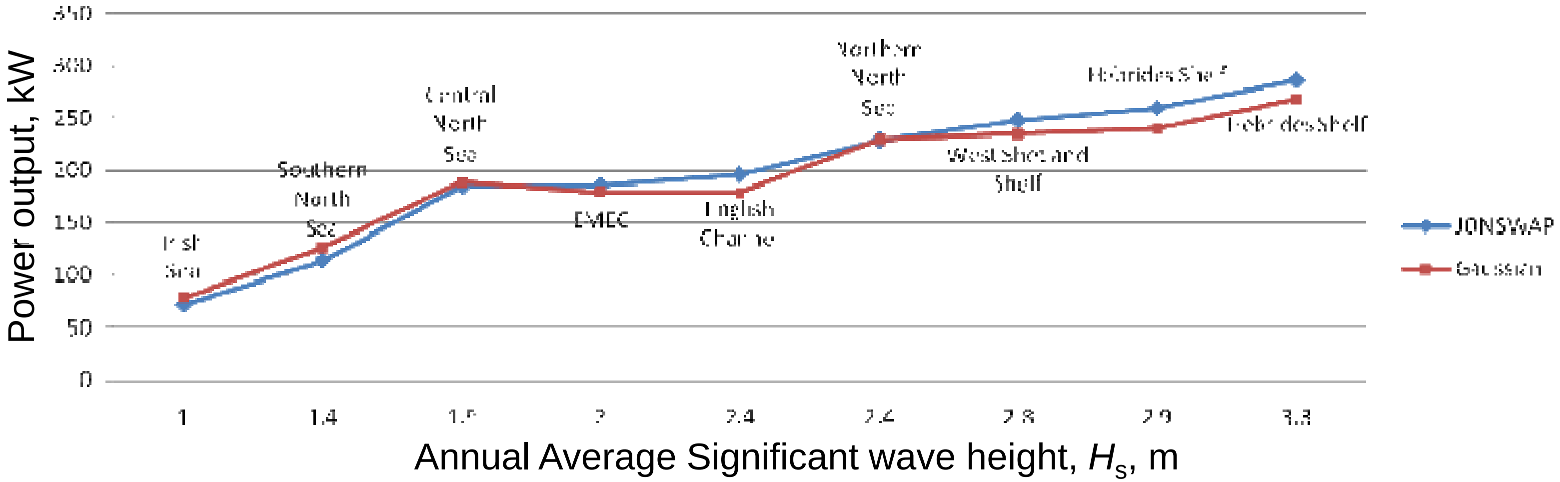


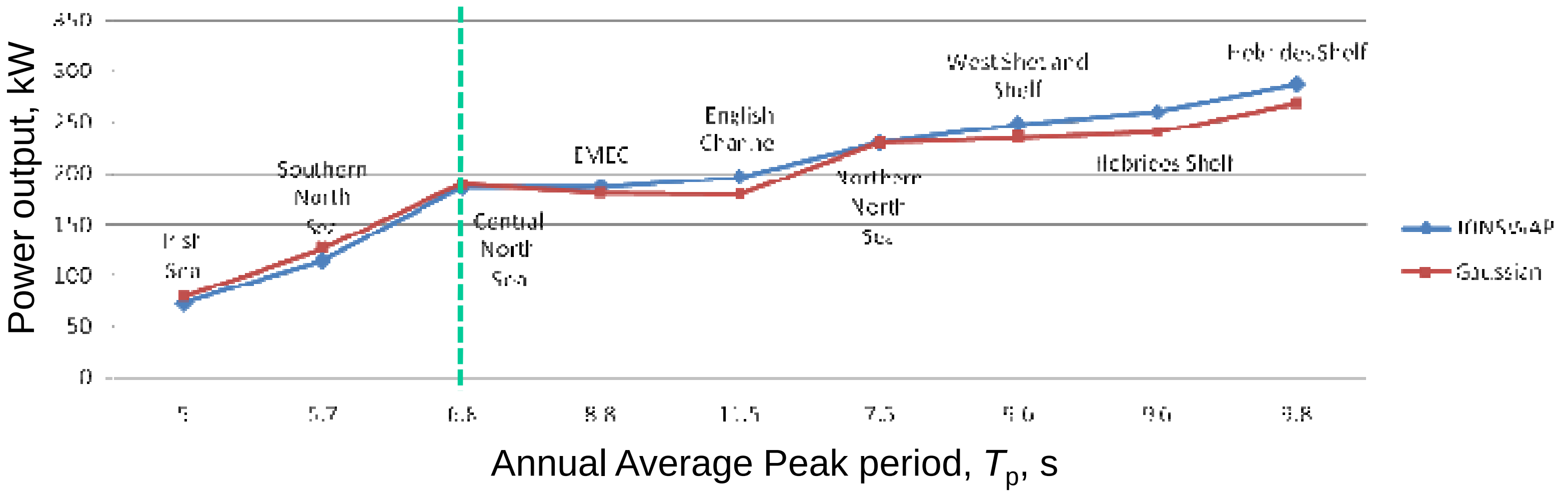
Mid-draft float



Weller, Stallard and Stansby, EWTEC 2009

Power output from 500 kW Bobber





Effect of Energy Extraction

PWP arrays at EMEC (Mike21, Venugopal & Smith. 2007)

Wavehub site and transmission sensitivity (SWAN, Smith et al. 2007)

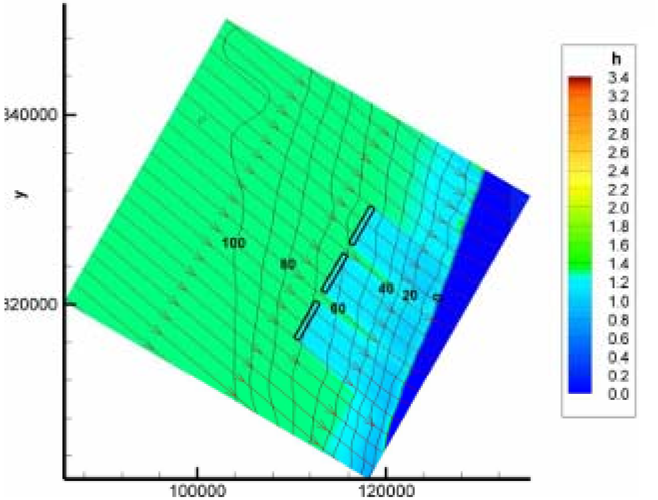
1.4 MW OPT array with 96% transmission (OLUCA-Spectral, Vidal et al 2007)

ΔH < 4% and reduction of sediment flux < 0.5 %

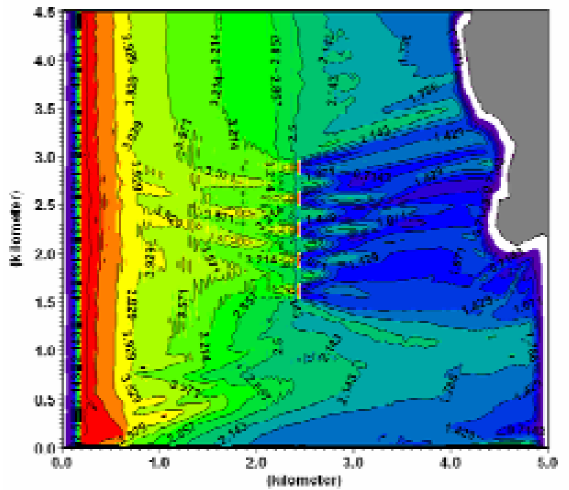
270 PWP devices at ~ 30 km from shoreline (REFDIF, Mendes et al. 2008)

ΔH < 20 cm

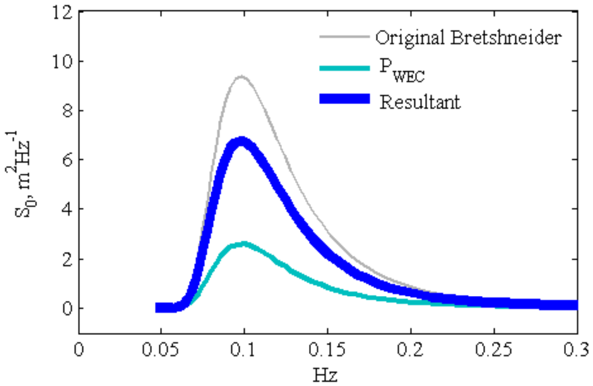
Typically constant transmission coefficients.



Portuguese Pilot Zone, Mendes et al. 2008.



Orkney. Venegupal and Smith (2007)



Alexandre, Stallard & Stansby (2009)

Summary

Tidal Stream

Technically extractable UK resource ~ 16TWh/yr

- at remote and/or deep sites, resource models are simplistic

Concepts converging towards 2-3 device types

- offshore feasibility demonstrated & attracting utility investment
- (much) closer to commercial viability than wave devices

Wave

Many device concepts

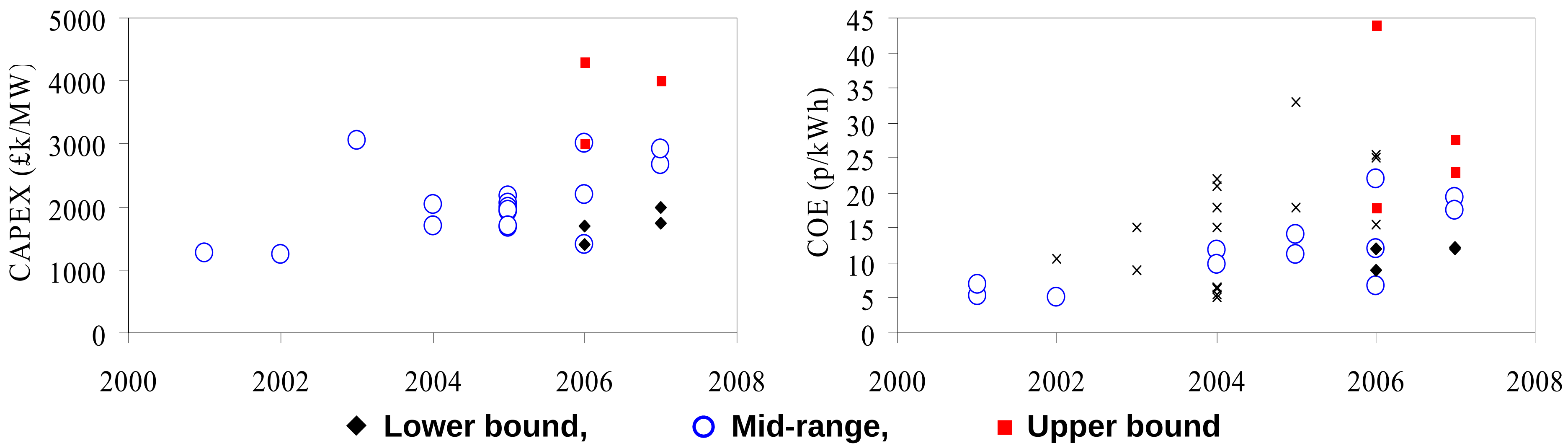
- Minimal full-scale testing (PWP and …?)

~ 20 concepts tested at 'scale' offshore

- Several structure supported concepts
- Relatively simple models of large-scale deployment

Marine Energy Costs

- WAVENET, Boud and Thorpe (2003)
- RAEng (2004) Cost of Generating Electricity
- Carbon Trust (2006) Future Marine Energy
- EPRI (2005-7)
- Ernst & Young (2007) Impact of Banding the ROC
- Renewables Advisory Board (2007) Marine Renewables



Thanks for your interest.

tim.stallard@manchester.ac.uk

School of MACE:	www.**mace.manchester.ac.uk**
NWDA Joule Centre:	www.**joulecentre.org**
FP7 Equimar:	www.**equimar.eu**
ETI, PerAWAT:	www.**energytechnologies.com**

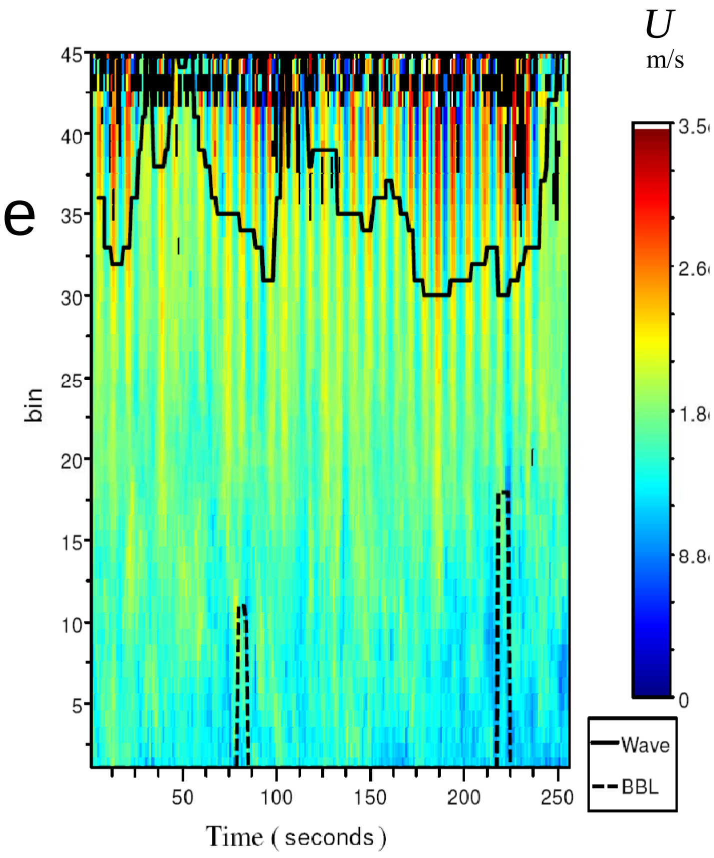
Turbulence Characteristics

- Turbulence Characteristics
  - Most analysis at *U* < 2 m/s,
  - Differs from atmospheric turbulence
    - Confinement, near surface stretching
  - Length scale disparity

    Free surface lid (Jirka, 2001 J.HydRes)

    $L_h \approx 6L_v$ (Stansby, 2003 JFM)

    L_v similar to ½ depth
  - Turbulence intensities
    - Variation with flow direction



Norris & Droniou, 2007, EWTEC