Dynamic performance analysis of tidal energy converters using acoustic sensors

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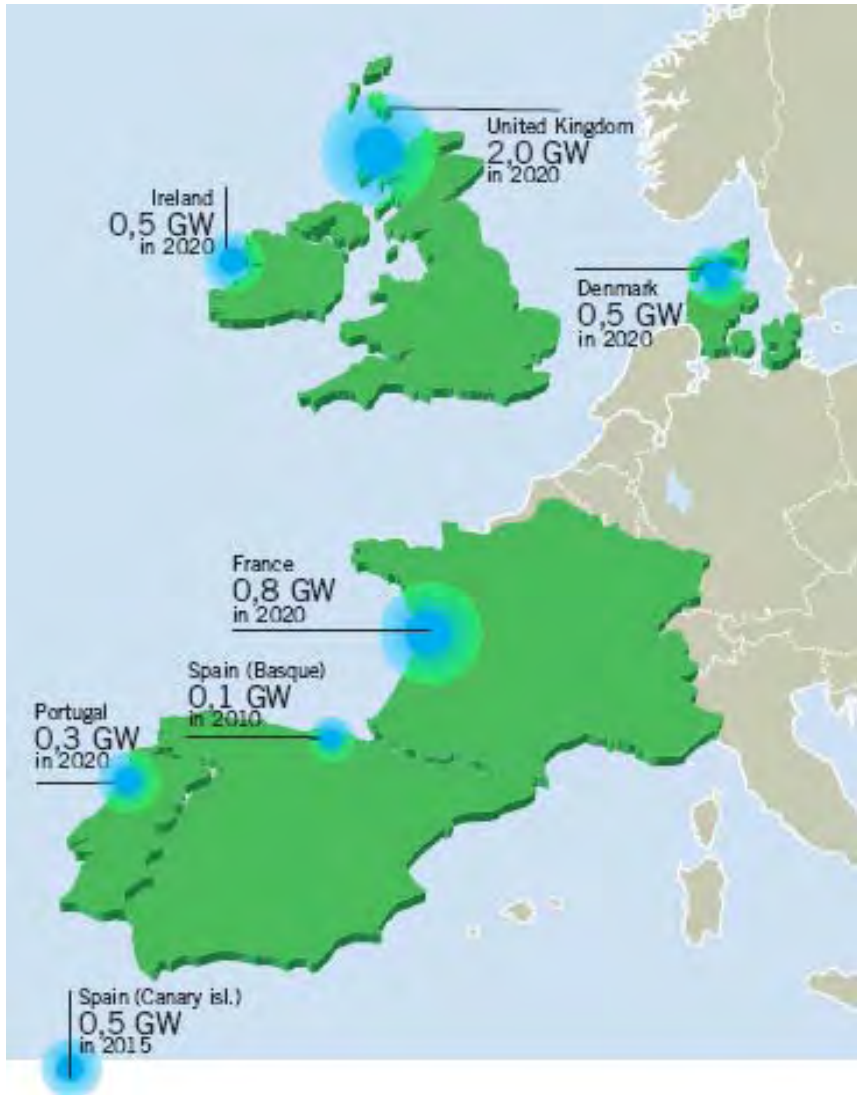
EUOEA: European Roadmap

Ocean energy in 2020

- 3600 MW installed
- 40000 jobs
- around 1% of EU electricity
- around 9 bn €uro/a investment

Ocean energy in 2050

- 188000 MW installed
- 470000 jobs
- around 15% of EU electricity
- around 450 bn €uro/a investment



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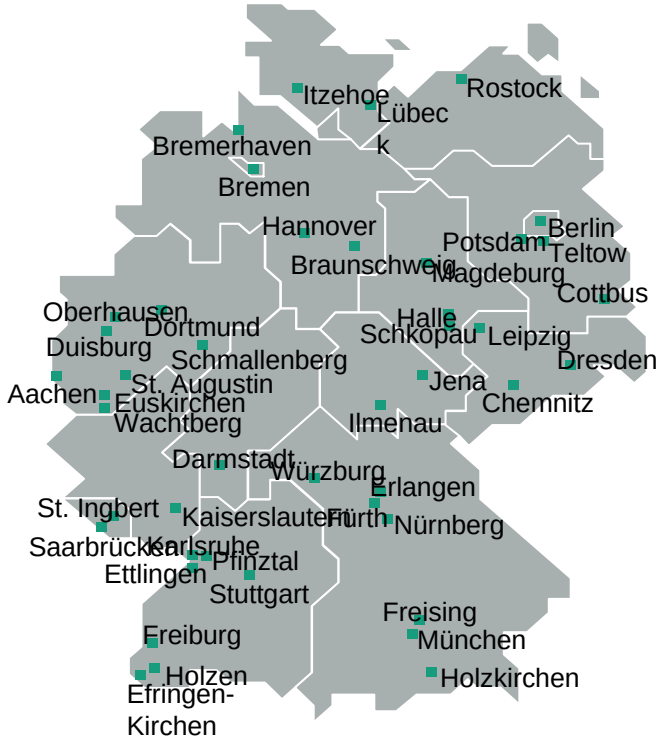
Fraunhofer-Gesellschaft

Europe's largest contractual research organisation



- 60 institutes at 42 locations
- > 17 000 employees
- 2009: 1.4 bn € turn over; with >500 M€. from industry
- Fraunhofer Energy Alliance
  > 1500 employees
  - Renewable energies
    - Photovoltaics, Solar thermal, concentrating solar plants
    - Biomass, biogas and bio fuels
    - Fraunhofer Wind Energy Network (6 institutes)
  - Efficient use of energy
  - Energy in buildings
  - Smart grids
  - Storage technologies

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IWES: a new Fraunhofer institute, founded in 2009

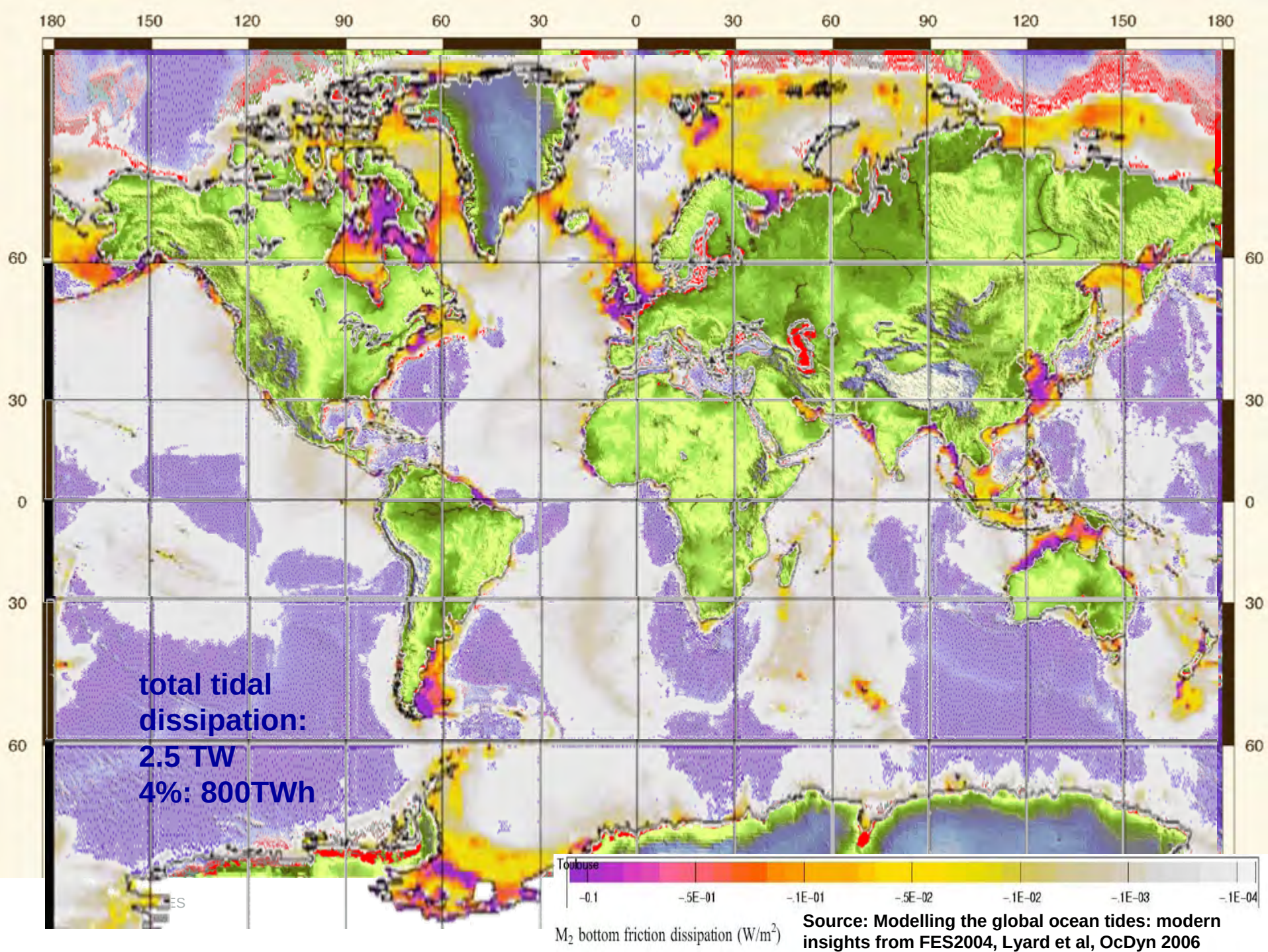
ISET + Fraunhofer Center Windenergie und Meerestechnik = Fraunhofer IWES

Applied Research for Wind Energy and Energy-System Technology for Renewable Energies

- Wind turbine technology:
  rotor blades, structures, pitch control, …
- On- & Offshore-wind energy exploitation
- Maritime environment (monitoring, sensors)
- Control & System integration
- Energy conversion systems
- Energy management & Grid operation
- Energy supply structures and system analysis

Overview of ocean energy activities

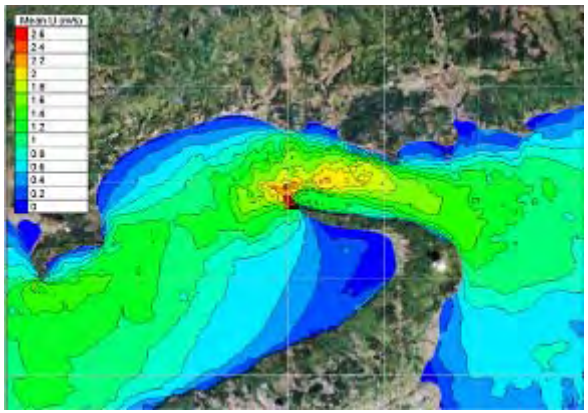
- **Technology development**
  SEAFLOW (2003), SEAGEN (2008)
  Kobold I (2007), Kobold II (2010)
  Pulse Tidal 1.2 MW Demonstration project (FP7 2009-2012)
  CORES – Components for Ocean Renewable Energy Systems (FP7 ’08-’10)
  SDWED – Structural Design of Wave Energy Devices (Dan. Res. Council)
  Marina Platform – research on multipurpose platforms (FP7 2010-2014)
  Wave Energy Feasibility Study for the German EEZ (Vattenfall)
  New concept for measuring currents, waves (WCI) and turbulence
- **Coordinating Research**
  Ocean Energy (www.wave-energy.net, 6. RP)
  ORECCA: Ocean Renewable Energy Conversion Platforms - Coordination Action
  Infrastructure Project for offshore Wind and OE - under negotiation
- **IEA**: Implementing Agreement Ocean Energy Systems (www.iea-oceanenergy.org)
- **IEC TC114**, German Mirror committee (DKE, VDE)
- **Publicity**:
  German Marine Energy Forum, since 2006
  International Conference Ocean Energy (ICOE) since 2006

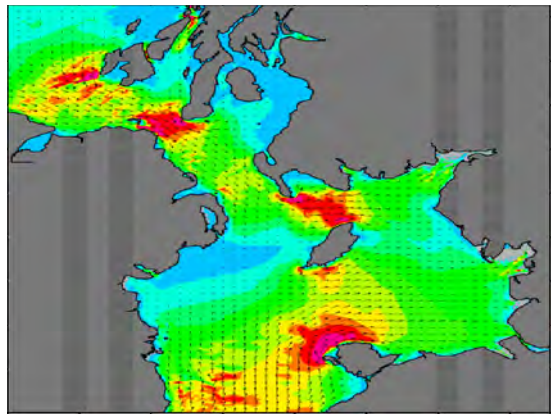


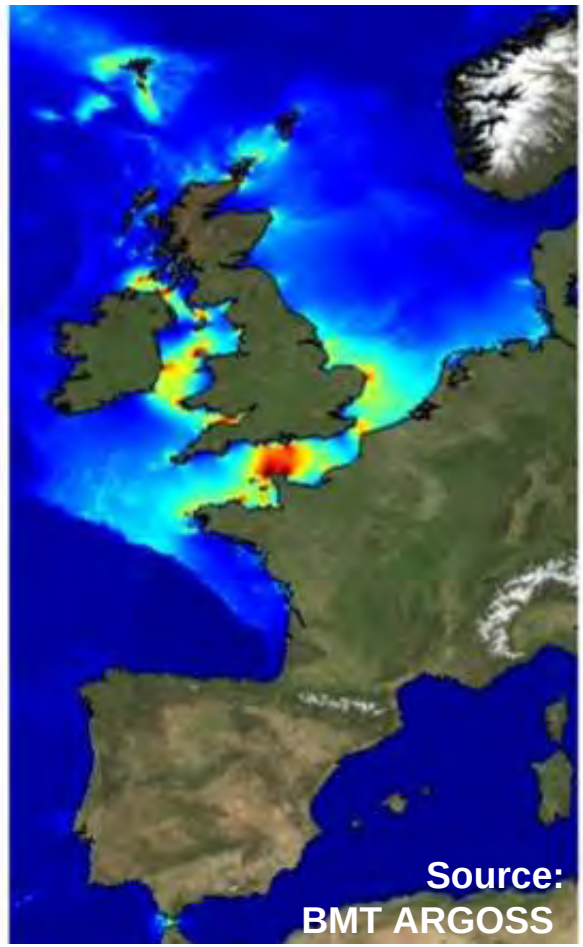
Source: Modelling the global ocean tides: modern insights from FES2004, Lyard et al, OcDyn 2006

Examples of tidal current resources

- Ireland: 230 TWh/a (theor.) 10 TWh/a (tech.)
- UK: 31 TWh
- France: 10 TWh
- Norway: 3 TWh Europe >54 TWh
- China: 50 TWh
- Korea: 100 GW („expected“)
- USA: 115 TWh
- Canada: >140 TWh







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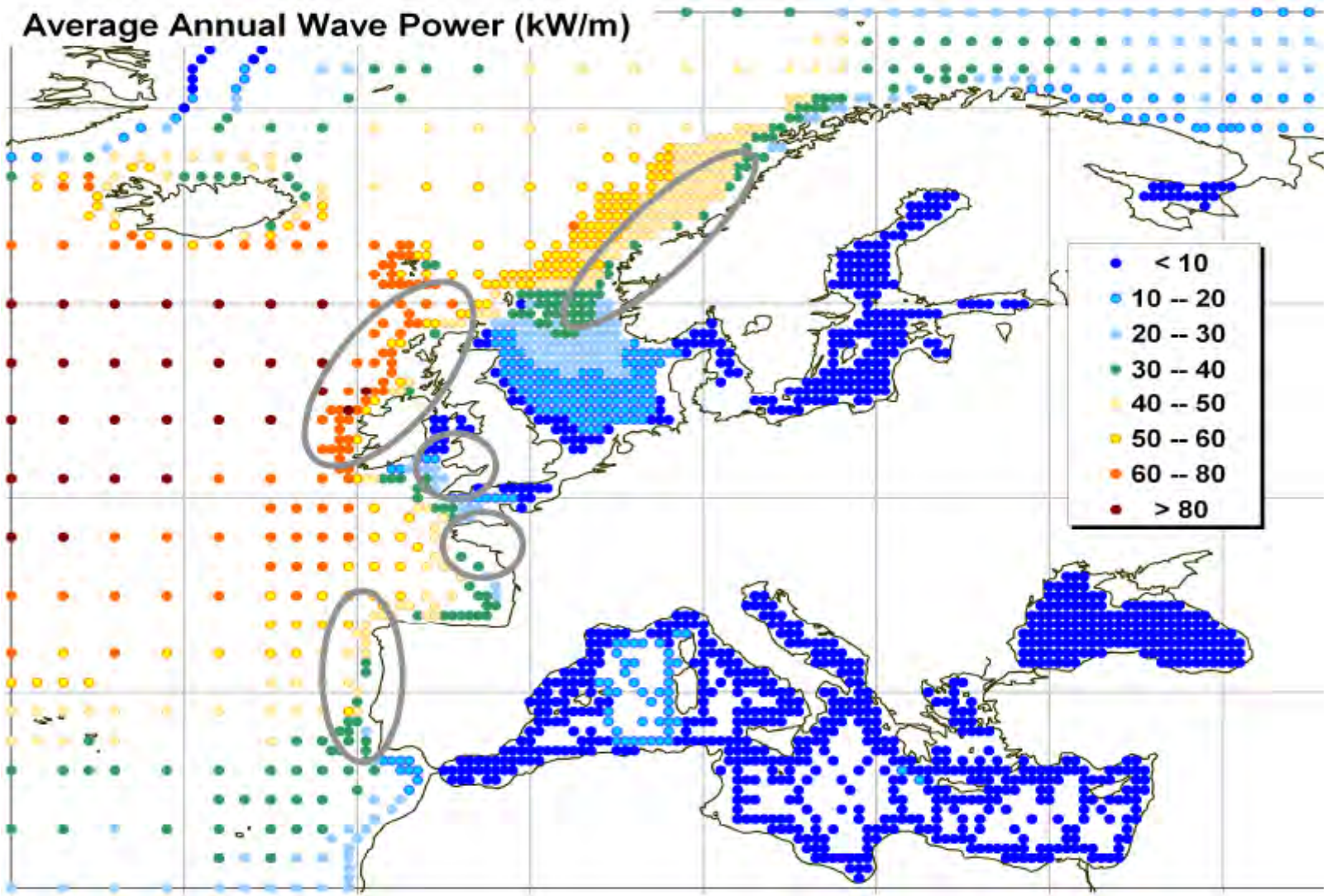
European Wave energy map (source OCEANOR)



a few hundred TWhs

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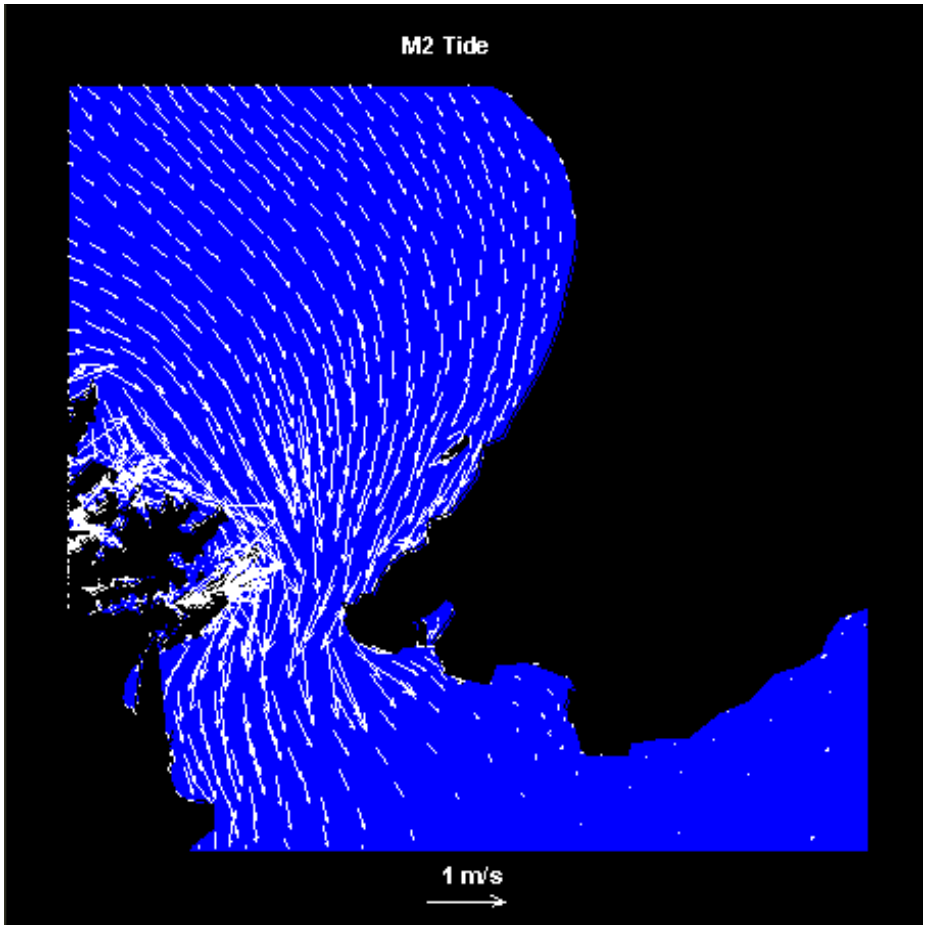
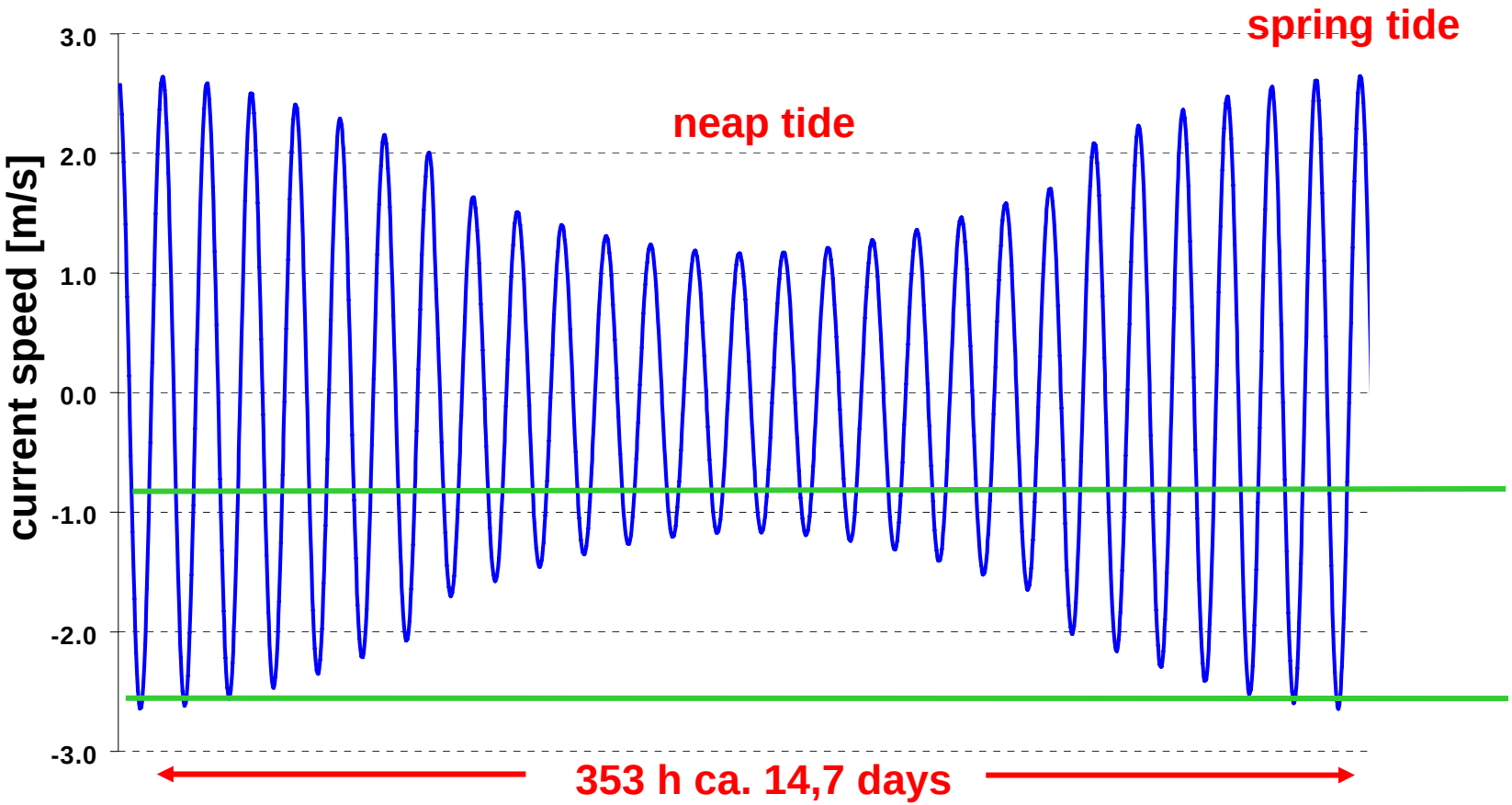
Tides as main drive for currents



example of tidal currents in the Cook Straight between North and South Island of New Zealand

Typical tidal current variations of a semidiurnal tide



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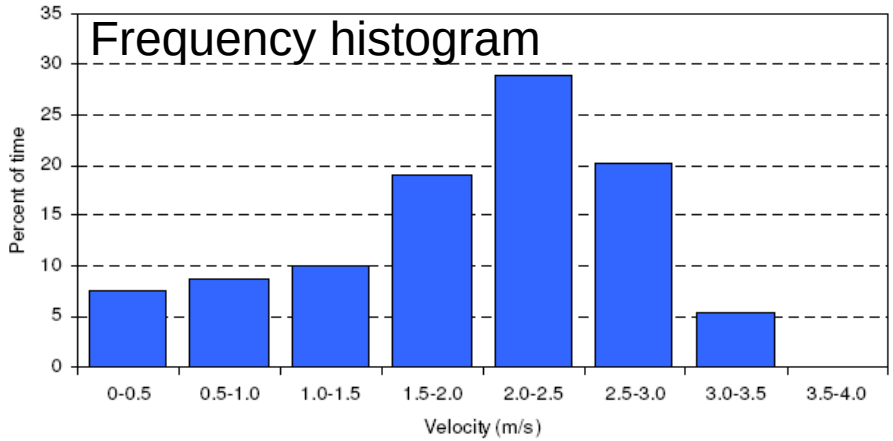
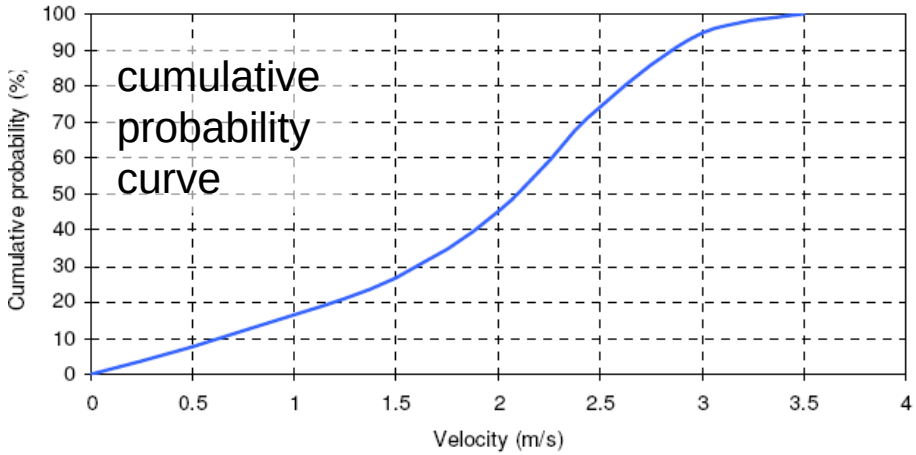
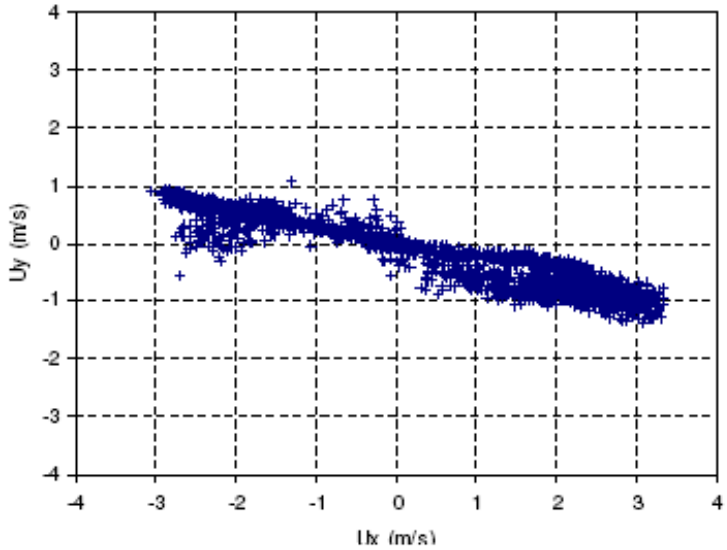
Data analysis from tide model: tidal current speed statistics







Tidal current ellipse

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Remote Sensing methods for surface current mapping

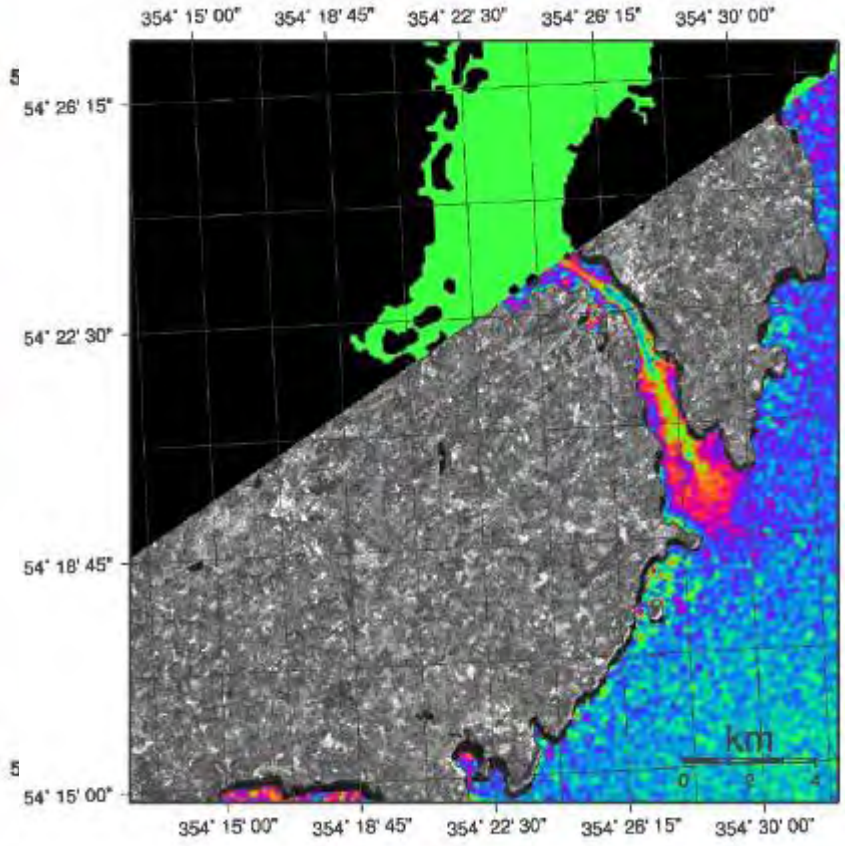
„velocity maps“ derived by special InSAR „Ocean- Processor“

SRTM – data Orkney islands
DLR, Oberpfaffenhofen

TerraSAR:
possibility of world wide surface current maps

Other airborn or landbased remote sensing Radar methods available

Very limited use in
tidal current exploitation



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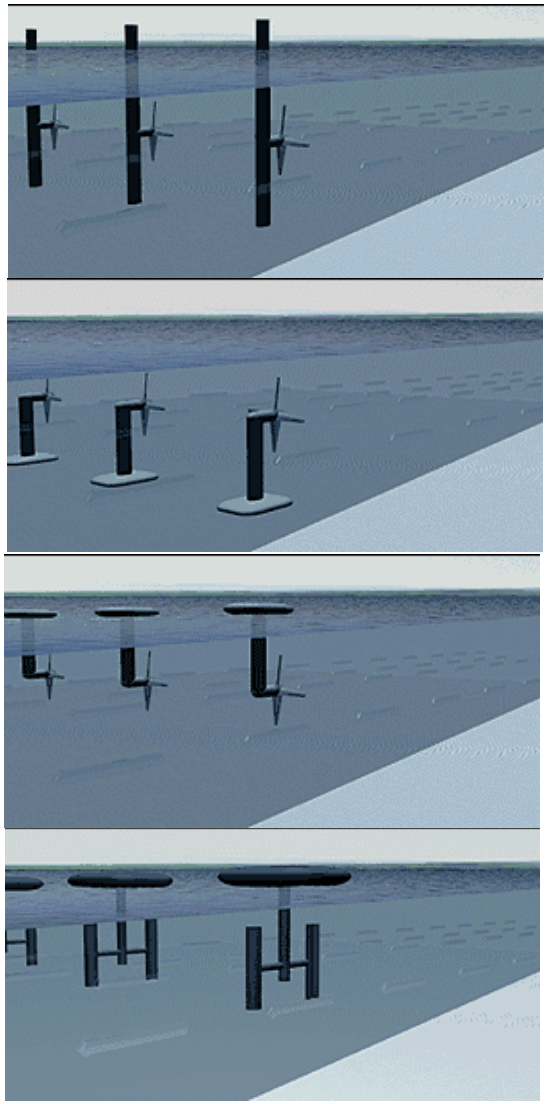
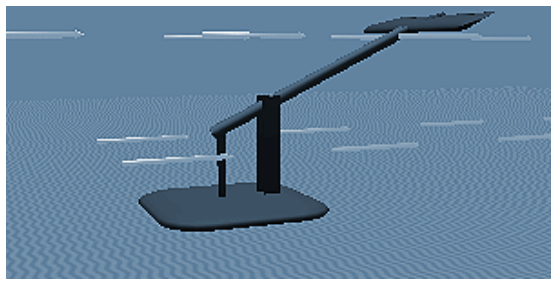
Technical aspects of existing tidal turbine concepts

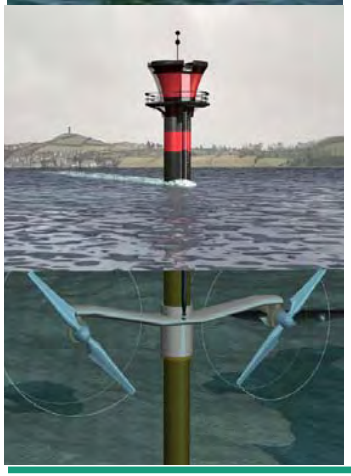
- drag-/ lift
- rotating/oscillating blades
- vertical/horizontal axis rotor
- axial /cross flow
- fixed / variable pitch
- one- or multidirectional operation
- free stream/ducted/tidal fence
- floating/ fix structure
- fully submerged/ lifting mechanism
- mechanical/hydraulic PTO
- fixed/variable speed
- …

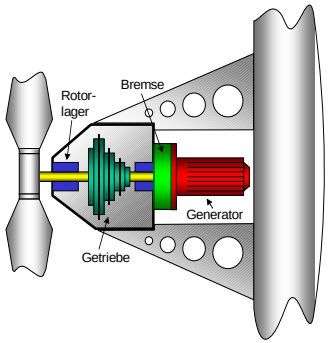


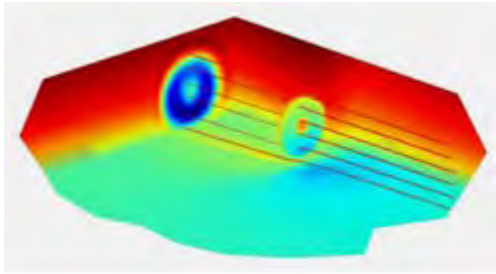
source.: EMEC



IWES ocean energy projects under German funding





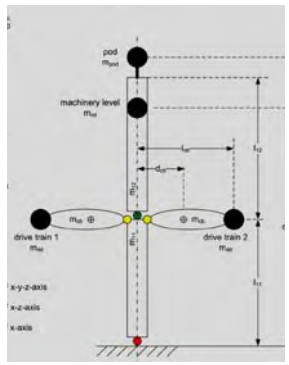


- dynamic simulations
- electrical engineering
- testing/monitoring

630 000 €
National funding
mainly for hardware

700 000 €
National funding
Partner: LTI (Pitch)

- advanced simulation model
- new pitch system
- drivetrain concepts



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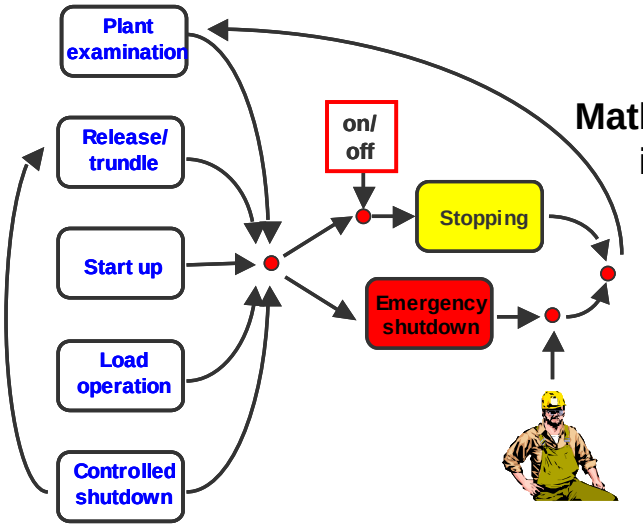
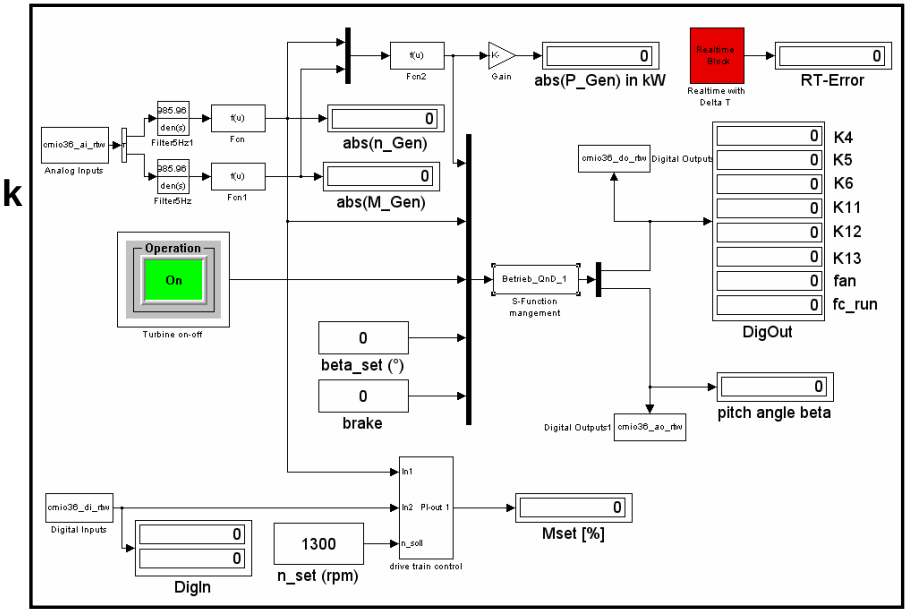
Control system development through dynamic simulation

- Based on a model library and work on
  load reduction controller for offshore multi megawatt wind turbines
- Performance and load simulations
- Operational conditions (start, stop, faults)
- Implementation in Matlab Simulink



Matlab Simulink interface



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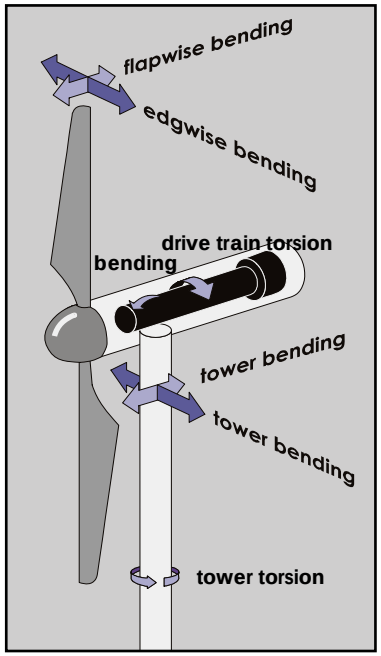
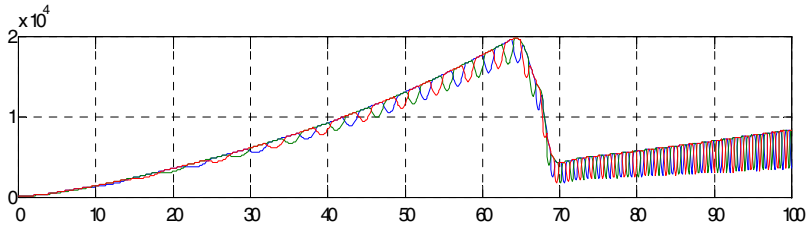
Load calculations through dynamic simulation

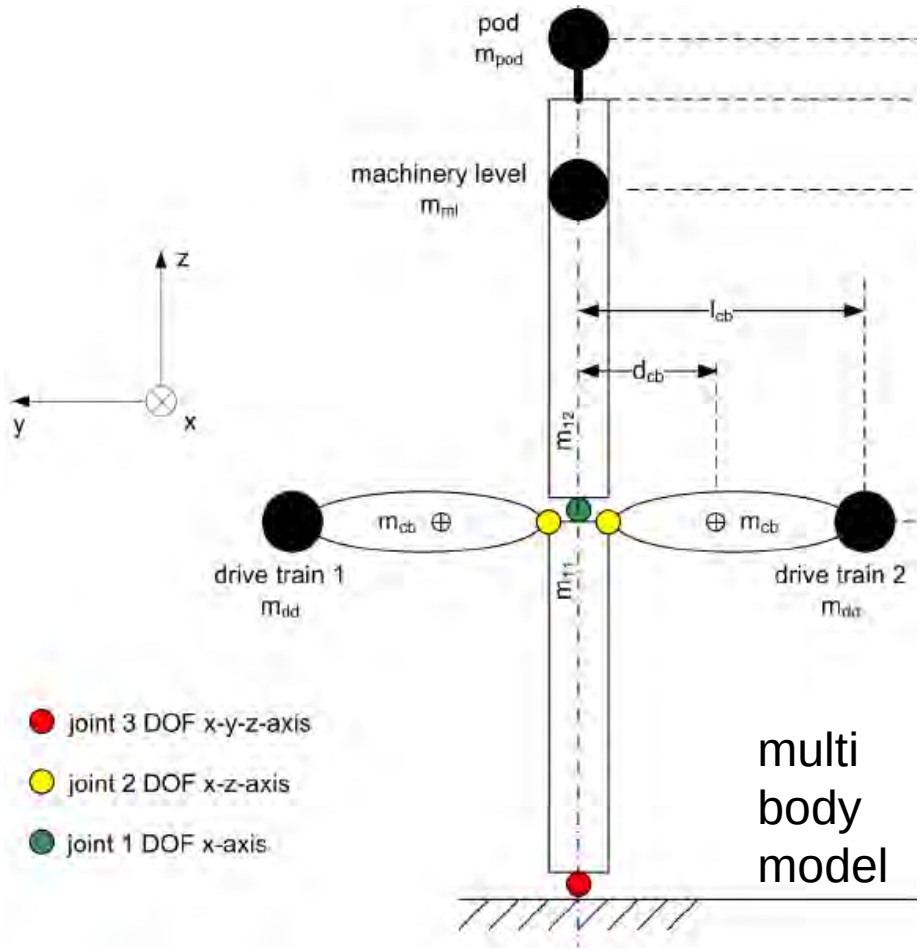
$$\psi = \arctan\frac{V_x - v_{i,ax}}{\Omega \cdot r + v_{i,tg}}.$$

$$\alpha = \psi - \beta - \vartheta$$

$$c = \sqrt{(V_x - v_{i,ax})^2 + (\Omega \cdot r + v_{i,tg})^2}$$







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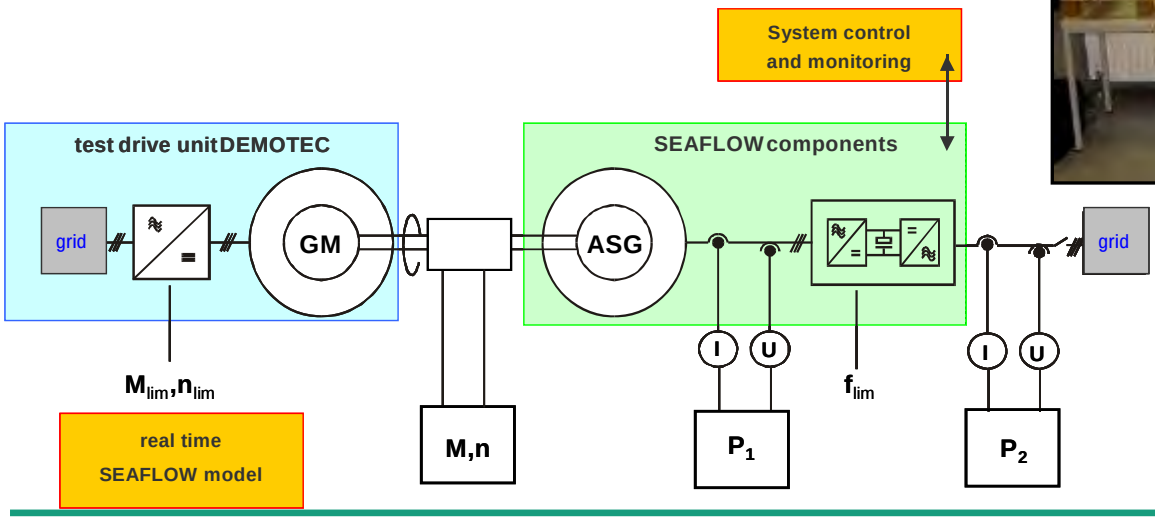
Control system development: experimental verification

- direct transfer of code into the control hardware
- electrical power and control systems in a HIL test
  - operating conditions reproduced
  - test of automatic operation
  - optimisation of control and electrical components



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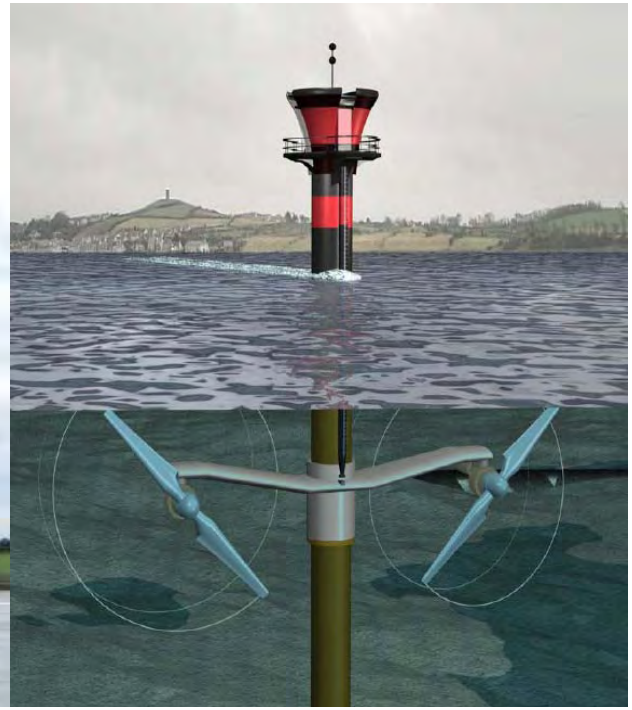
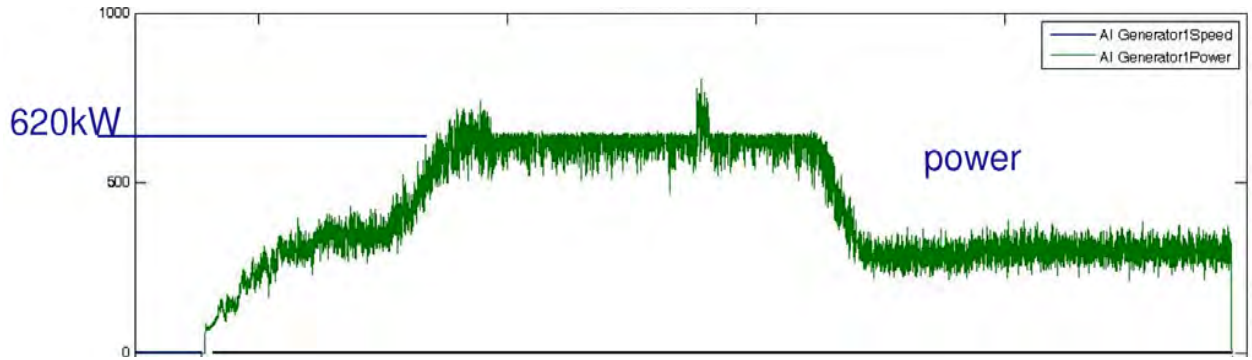
SEAGEN device

1.2 MW
Twin rotor





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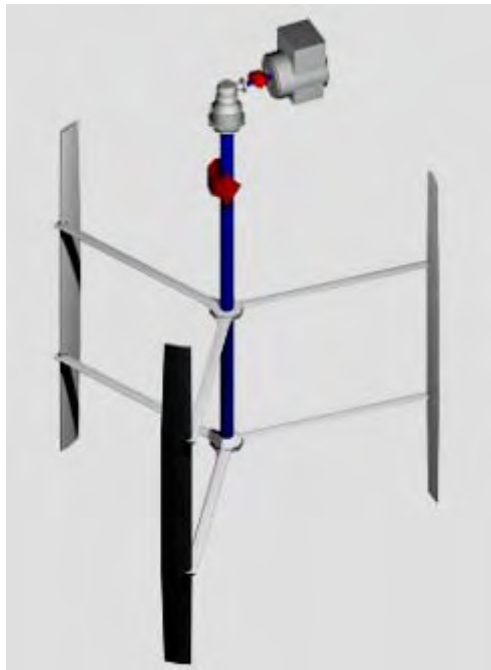
Kobold I & II

„Kobold 1“
Turbine
Ponte di
Archimede



Kobold II:
150 kW – device for
village electrification in Indonesia (hybrid system)
funded by UNIDO

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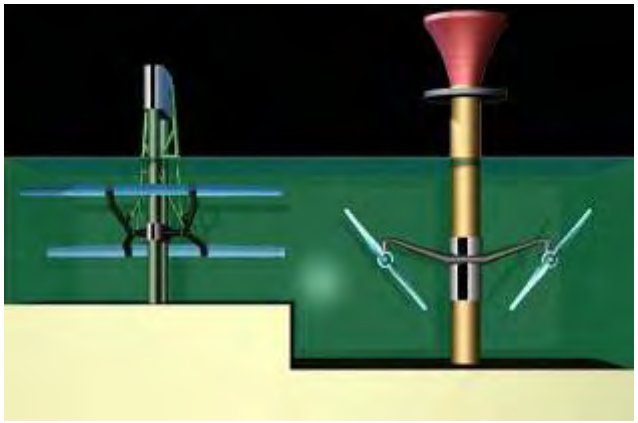
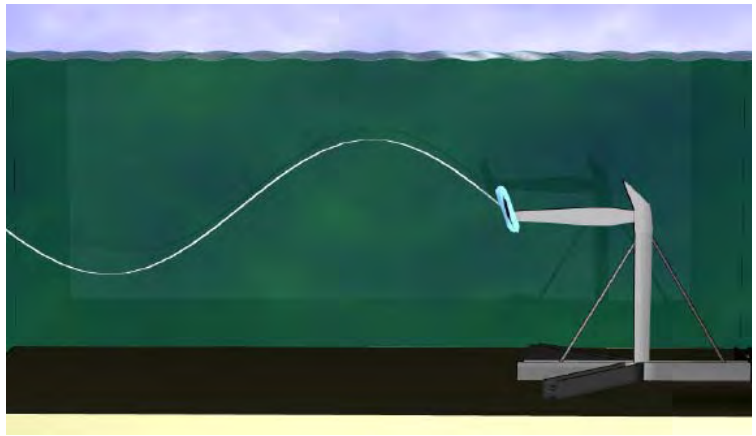
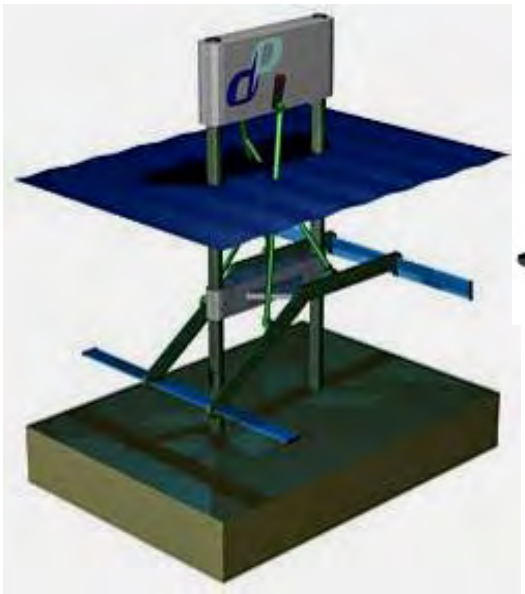
Pulse Stream 1200: 1.2 MW EU-Demonstration project



shallow water technology





Pulse Tidal Generation
150 kW scaled test
in the Humber

Turbulence in tidal currents

Saltstraumen sound, 30 km east of Bodø, Norway

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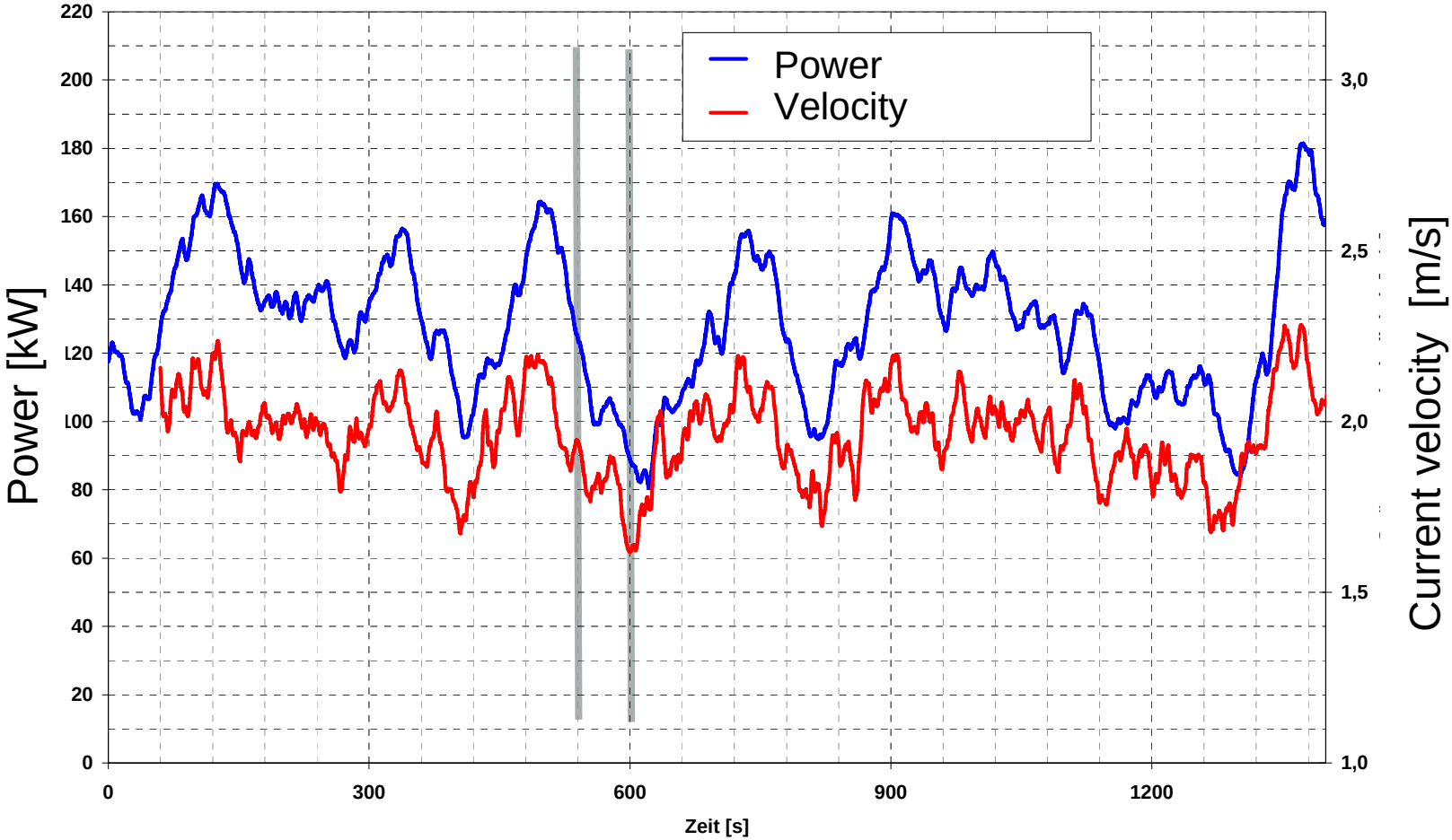
Operational results: turbulence!



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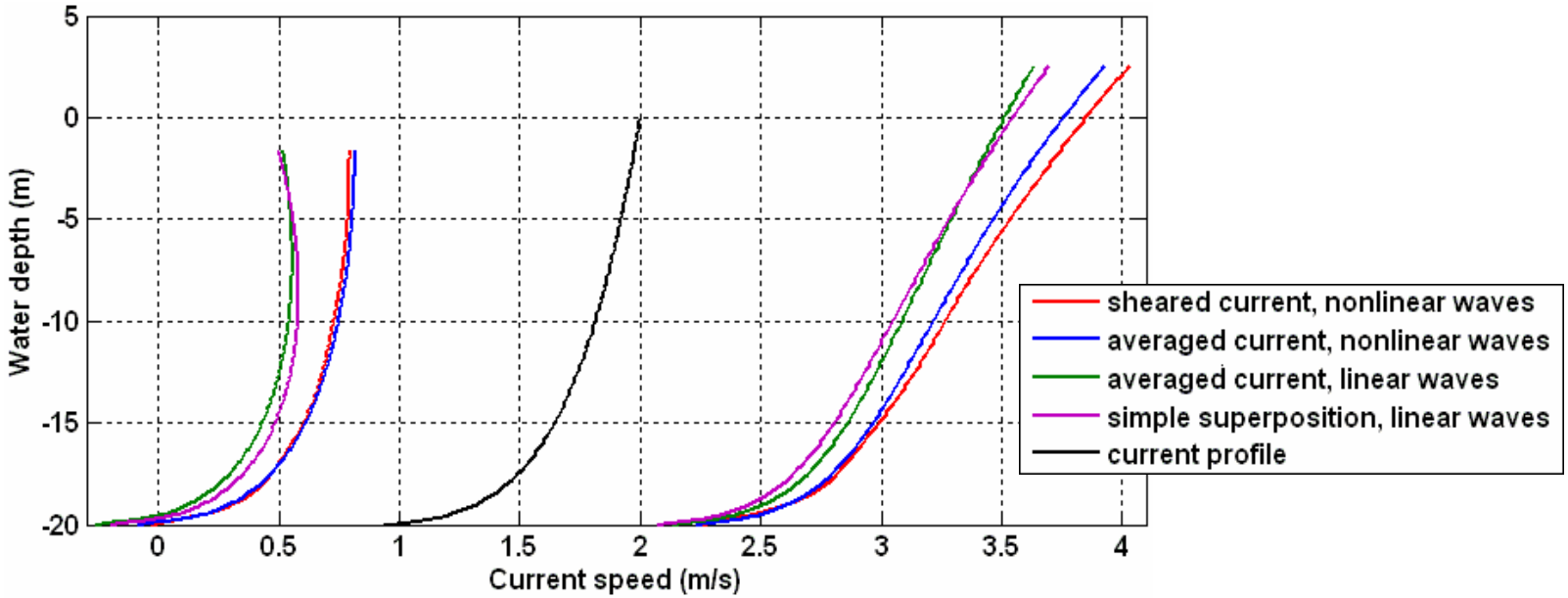
Wave Current Interaction (WCI): dominating fatigue load

- Modeling and Simulation:
  different levels of complexity of existing models
- simulations under different conditions
- investigation of the relevance for tidal energy extraction ongoing



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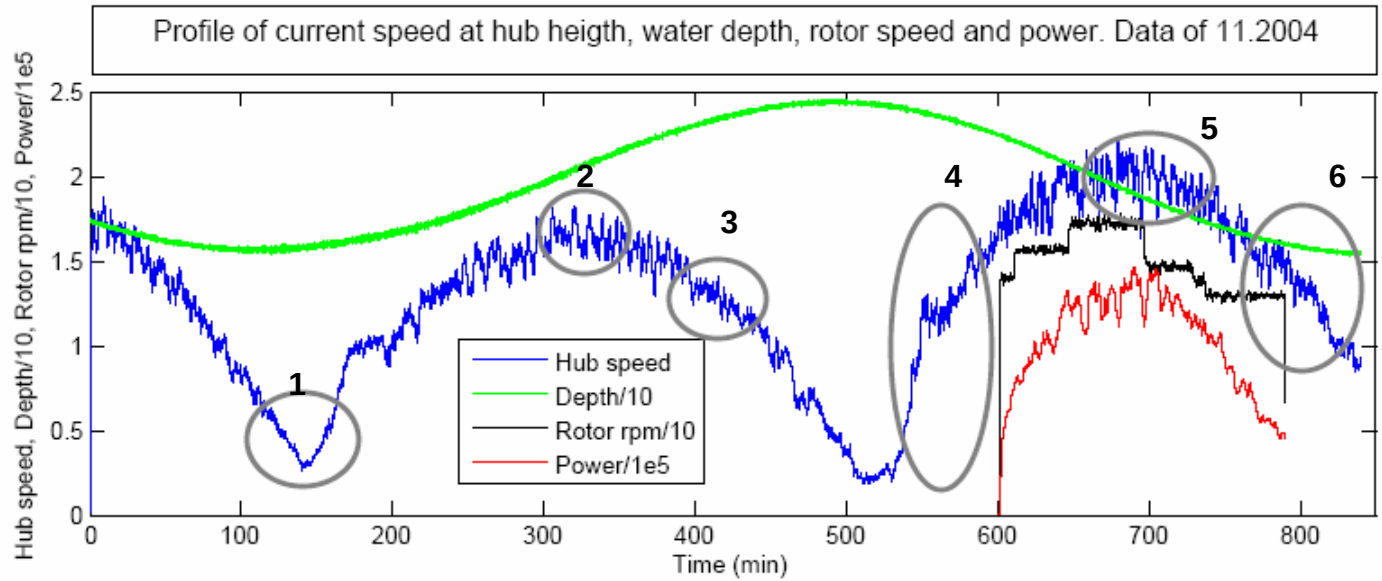

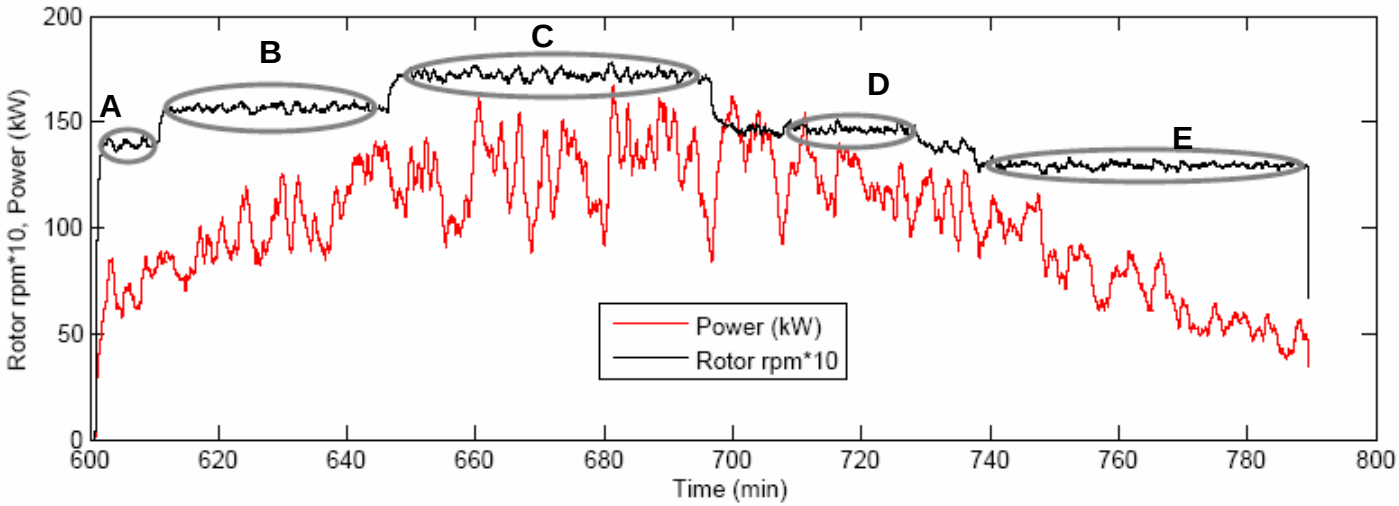

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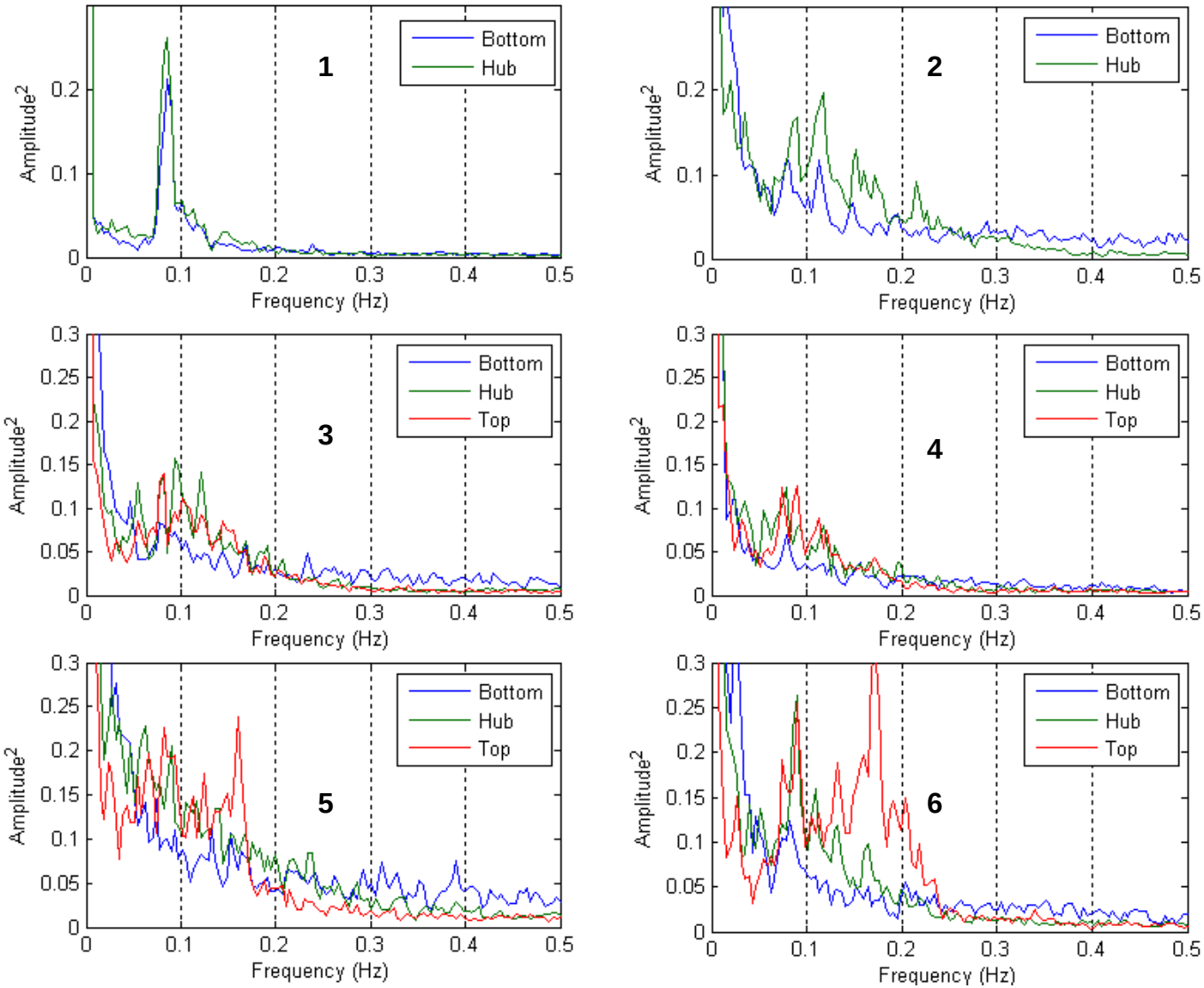
Current speed PSD in different time intervals at the rotor bottom, hub and top. Data of 11.2004



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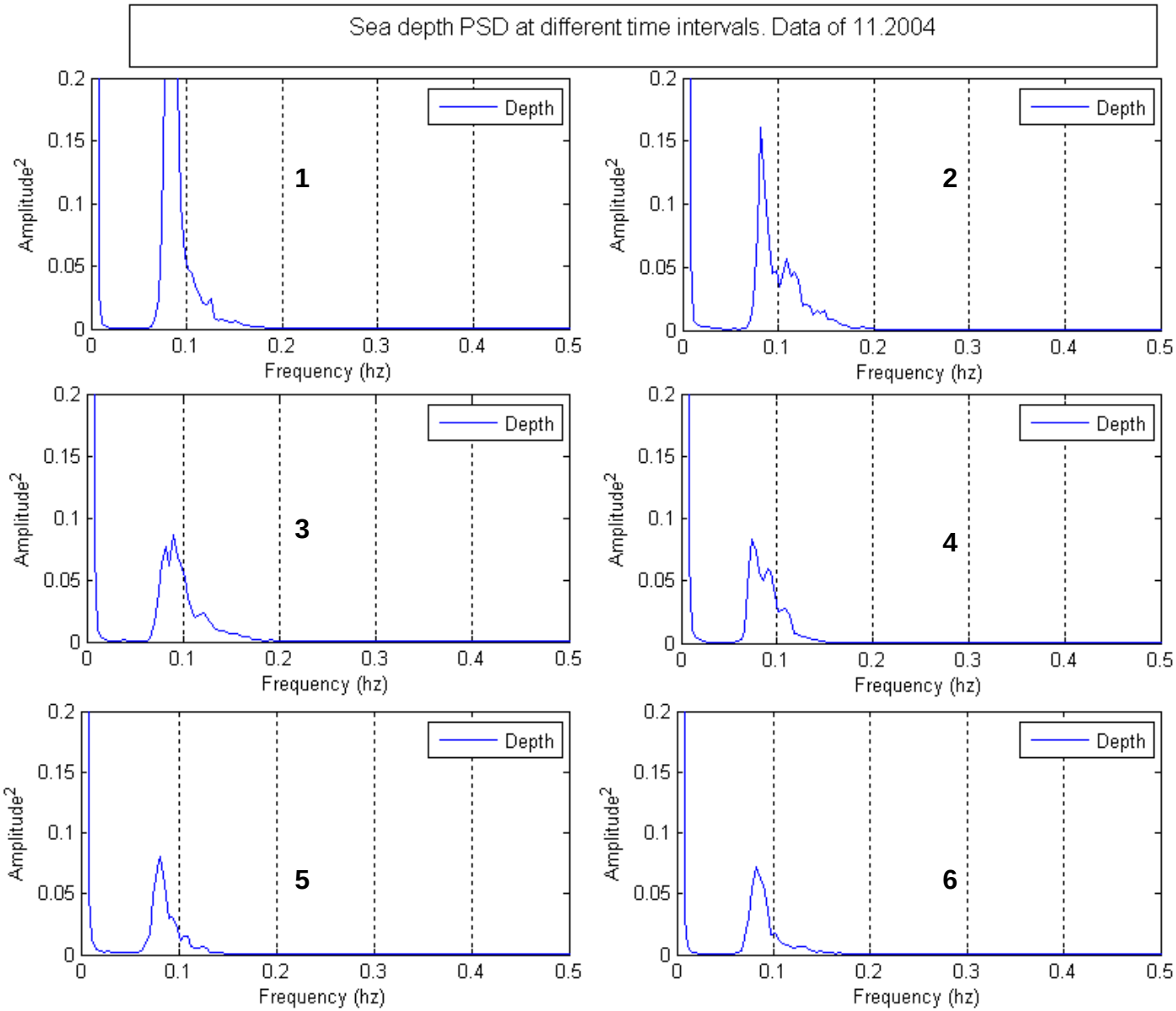

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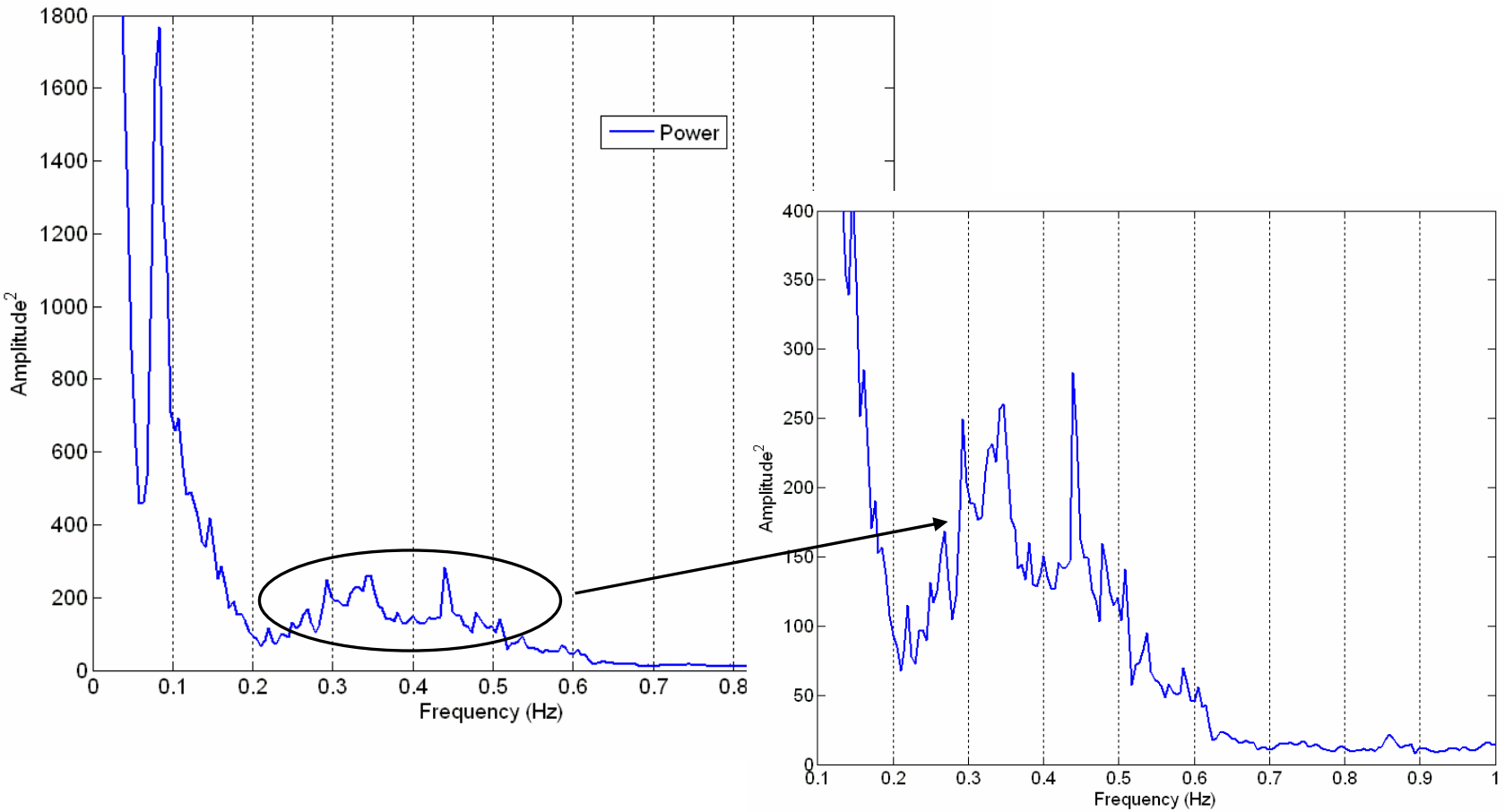
Rotor power PSD over the entire cycle



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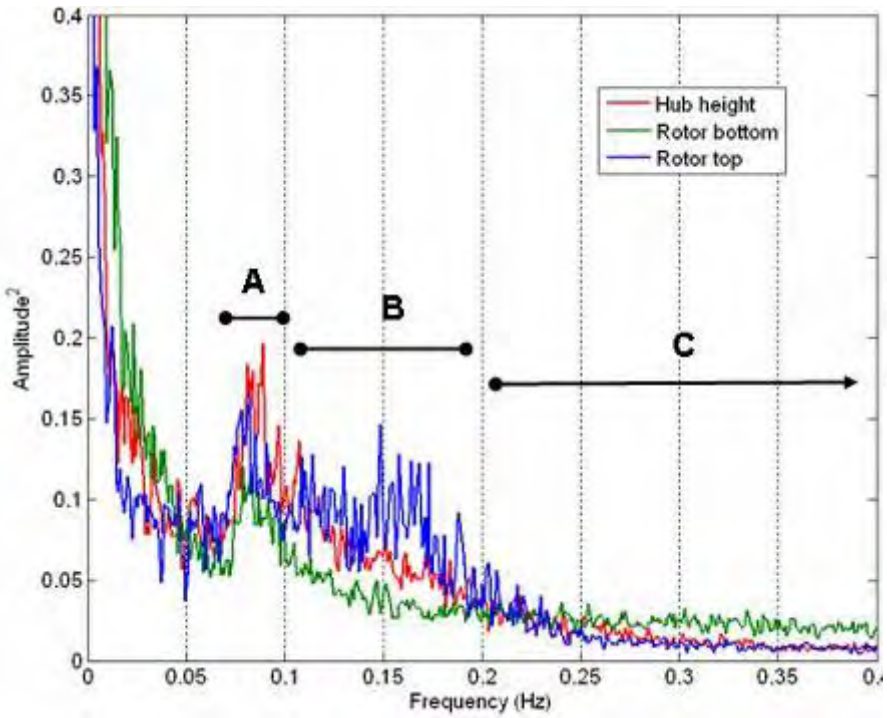
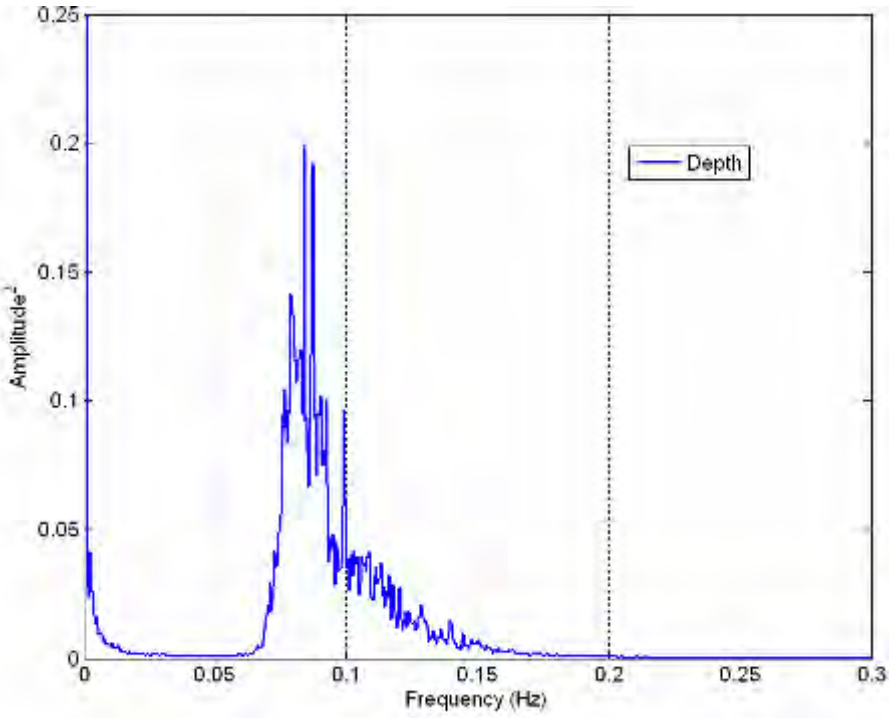
Improved measurements and analysis required!

Current speed PSD



Water depth PSD



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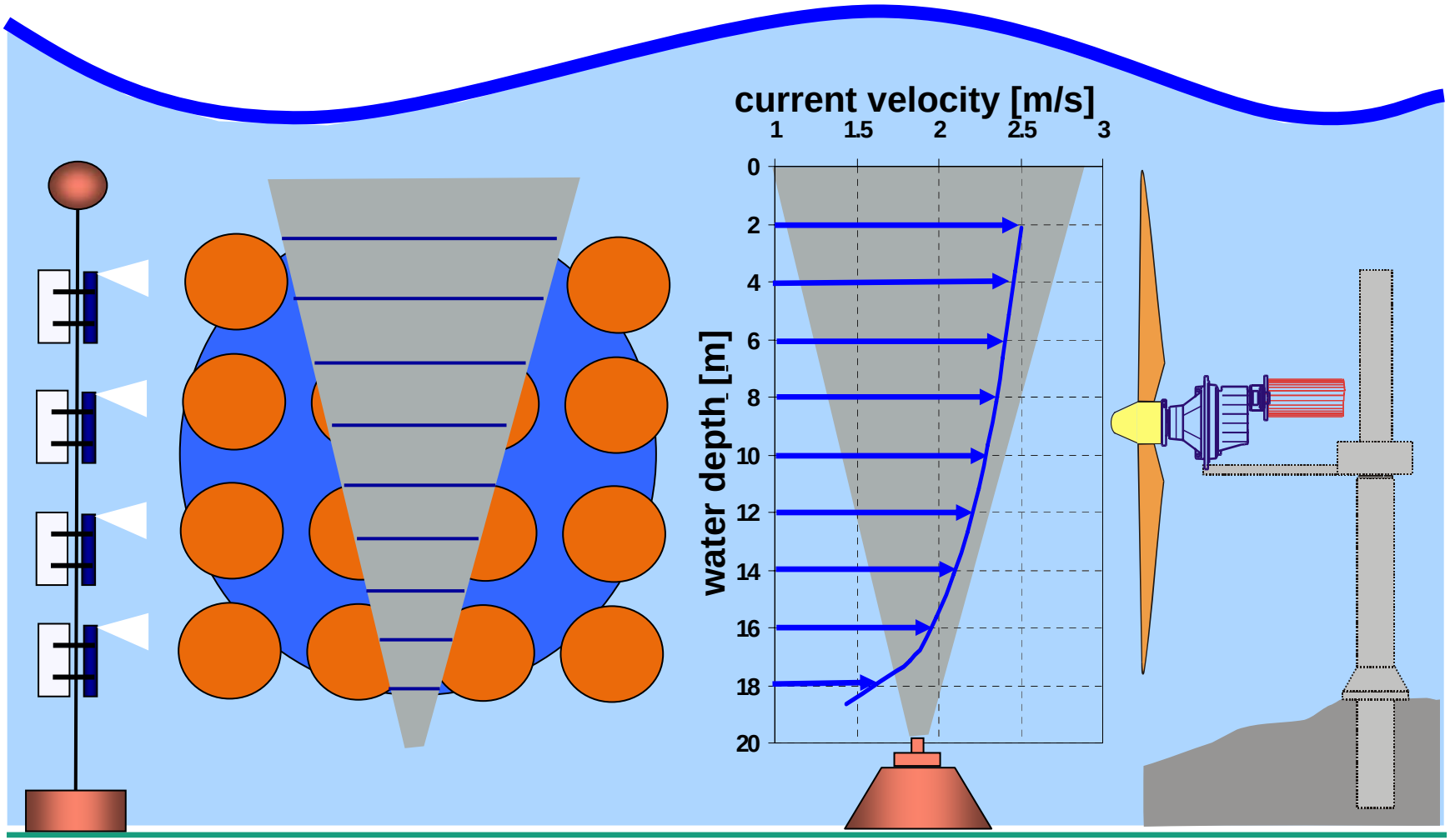
Single acoustic profiler vs multiple sensor array



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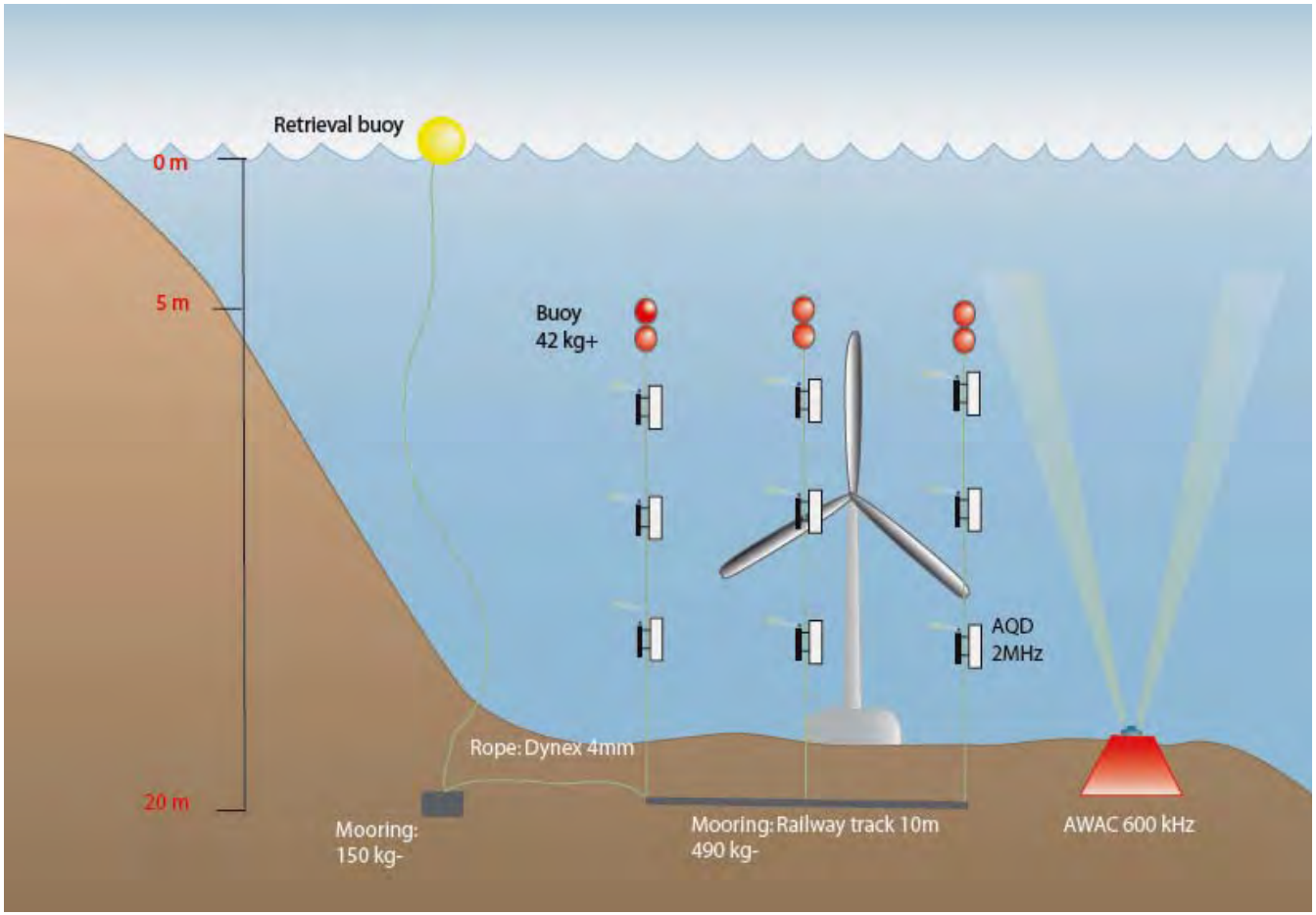
Development of a new concept for the combined measurement of currents, waves and turbulence
- based on Nortek's acoustic devices Aquadop and AWAC



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Summary

- Detailed characterisation of sites
  - Including current profile, waves, turbulence
- Detailed monitoring of full scale tidal energy conversion devices (standards)
- Improvements on WCI and turbulence models
- Calculation of fatigue loads
- Improved structural design and control engineering solutions
- Cost reduction and improved energy yield