High fidelity tidal turbine and coastal modelling

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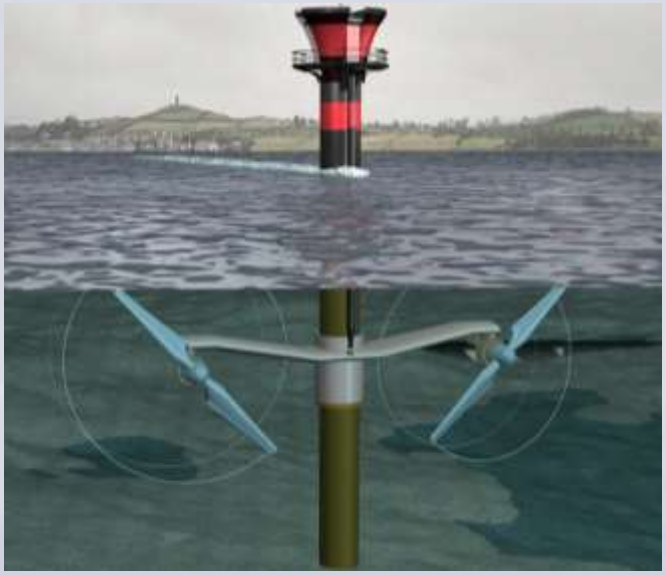
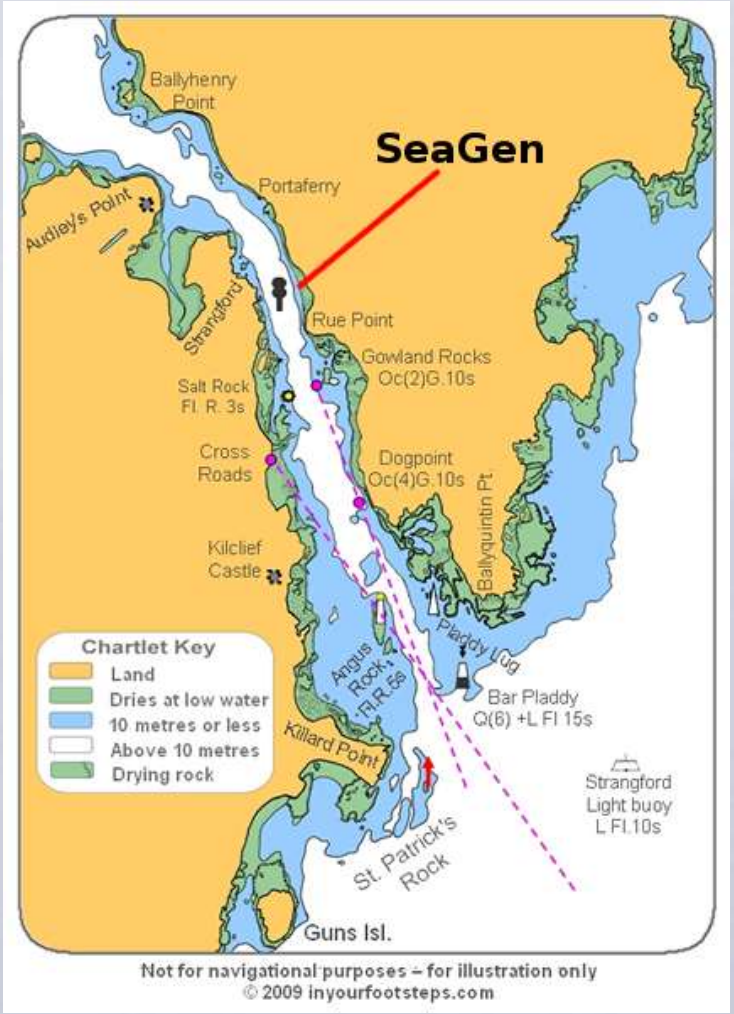
Tidal turbine modelling on FLOWBEC

FLOWBEC project



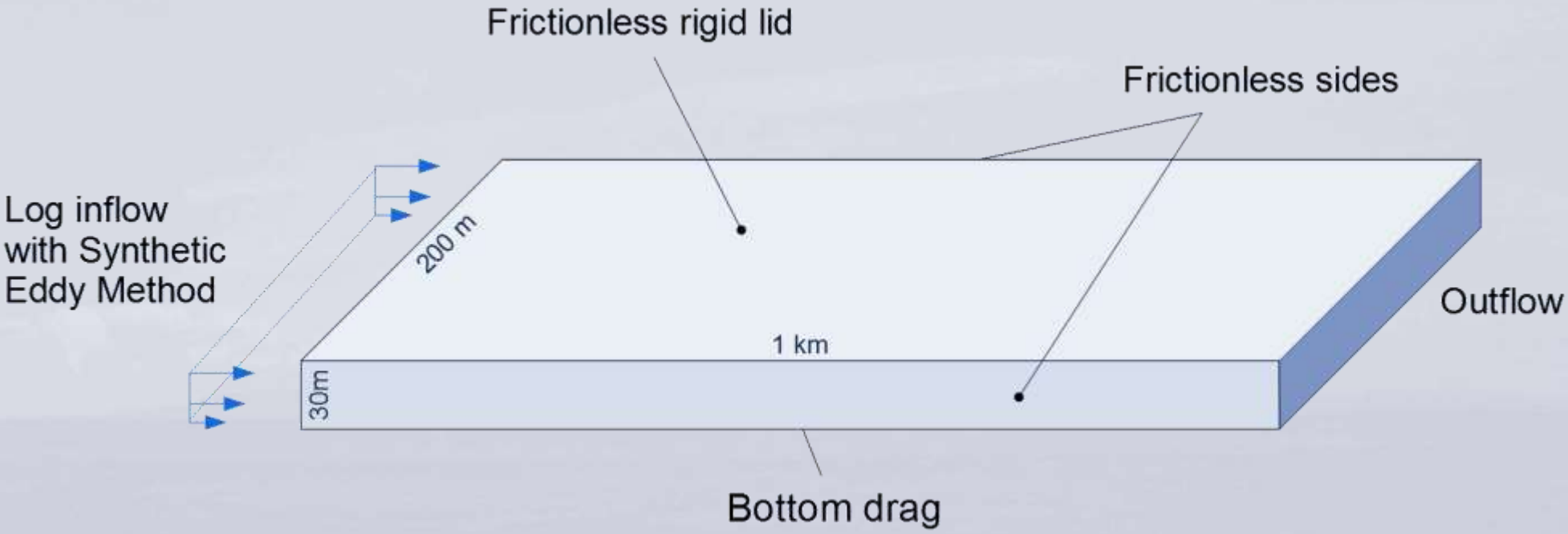
- NERC-funded environmental impact assessment of tidal turbines
- Partnership with Queen's University
- Strangford Lough, Northern Ireland
- MCT SeaGen
- SeaGen is a dual rotor tidal turbine



Modelling goals

- Model the downstream wake from a SeaGen-like (dual rotor) tidal turbine
- To provide detailed information on transient structures
- To examine contribution of both rotors and structure to downstream wake

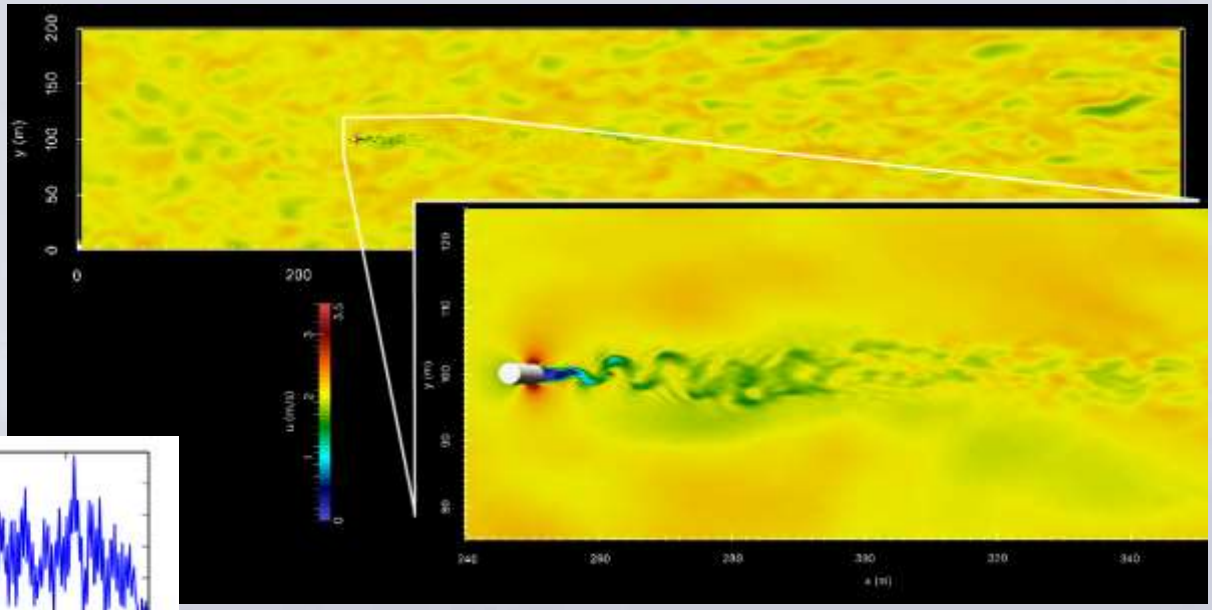
Channel domain

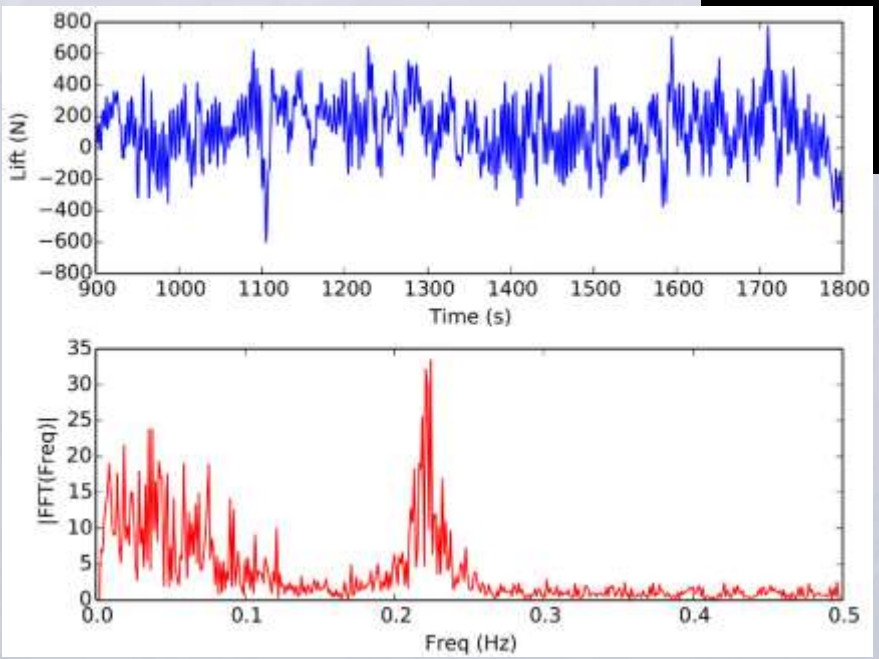


- Idealised domain to remove bathymetric effects
- Long domain to capture downstream wake
- Large-Eddy Simulation turbulence modelling
- Turbulent inflow boundary conditions (Synthetic Eddy Method)
- Drag condition at seabed

Test case :: flow round a cylinder

- Vortex shedding at regular frequency
- Fluctuations in lift
- Re = 3.4 x 10^6

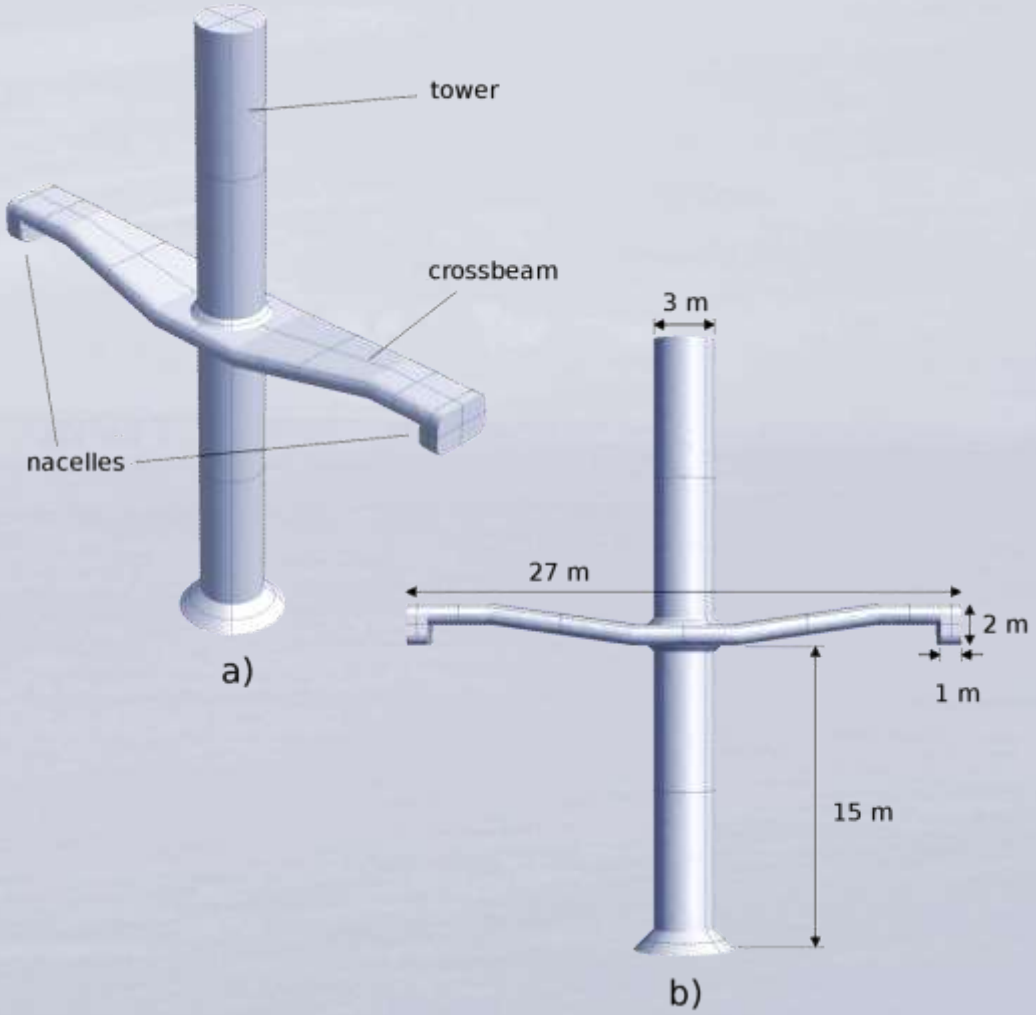




- Strouhal number St = f D / U
- Model gives St = 0.33 – 0.3375
- Good agreement with experiment

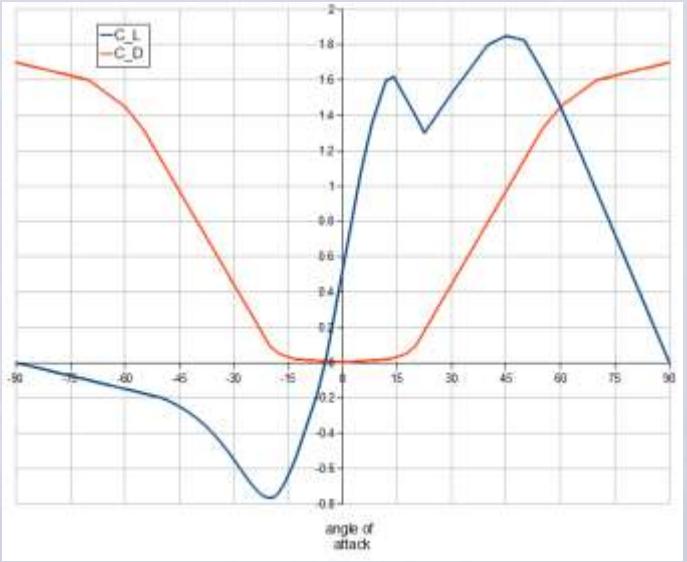
Turbine design :: structure

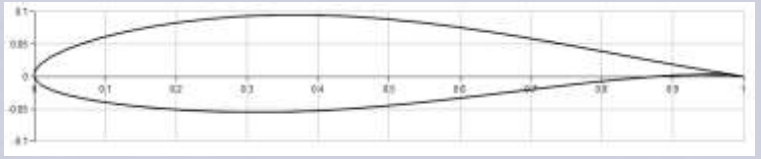
- Based on SeaGen
- Using public data
- Crossbeam supports rotors: over 1m thick
- Nacelle 1m x 1m cross-section
- Surface-piercing tower 3m in diameter



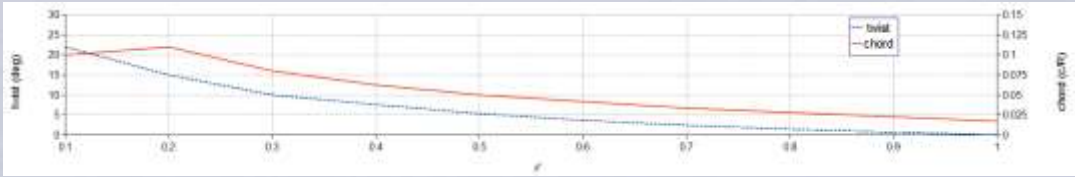
Turbine design :: rotors

- Pair contra-rotating rotors (16m diam.)
- Each rotor has two blades
- Rated power output 1.2MW
- Active pitching mechanism
- NACA 64-3xx aerofoil types
- Chord length, blade twist calculated from TSR





- Modelling components:
  - actuator line theory
  - torque-controlled generator
- More details:
  - Sorensen et al 2002, Troldberg
  - Creech et al 2011, 2014



Simulations :: overview

- Three case studies:
  i) Turbine rotors only
  ii) Turbine structure
  iii) Rotors + structure

- 900 s of ‘spin-up’ simulation time

- Further 900 s for analysis

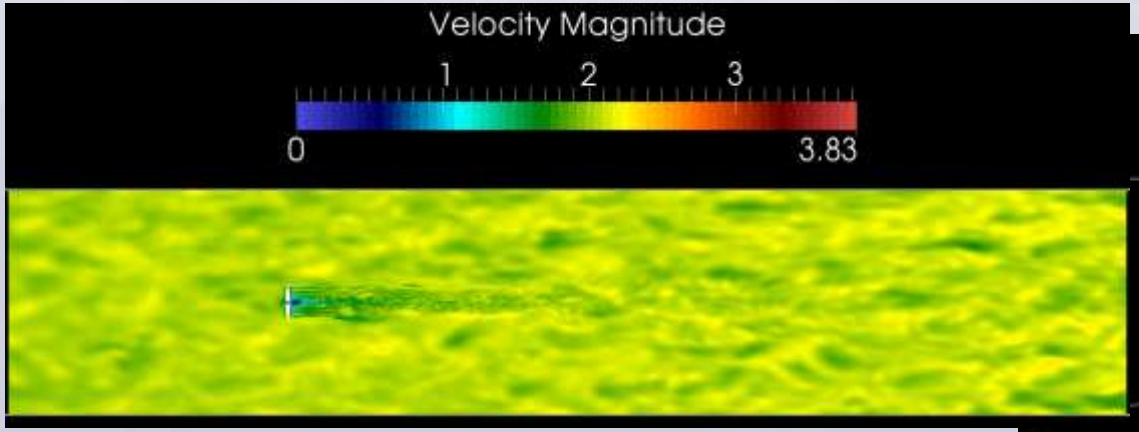
- Adequate? Perhaps not, but v. expensive to run

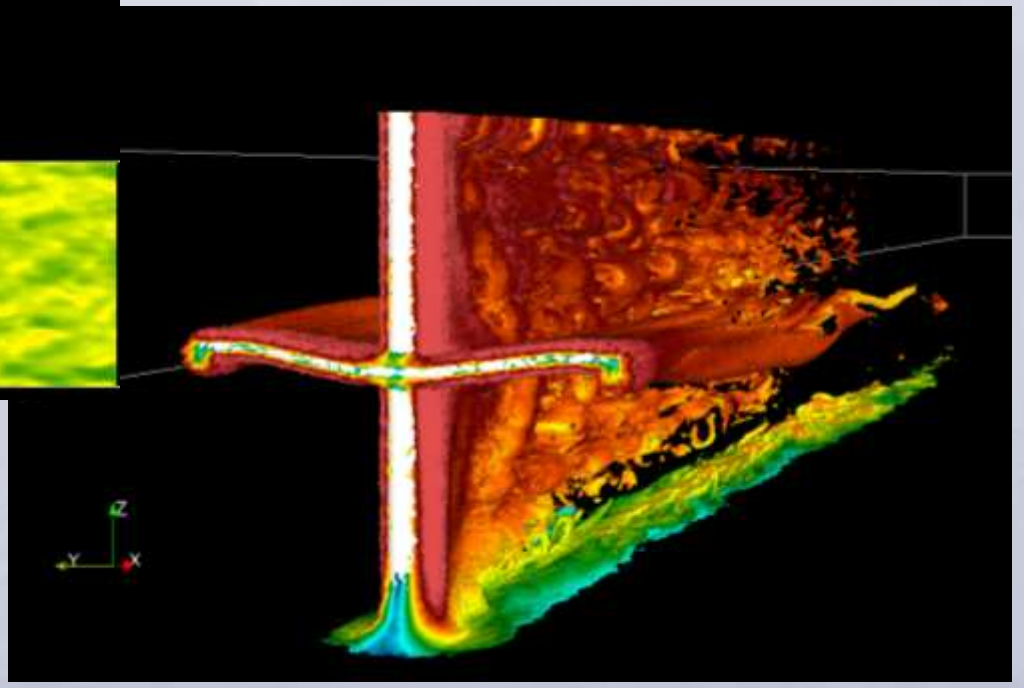
- Typical run 2400 computing cores, for 1 week per case

- Finite element CFD w/ Fluidity: P1-P1CV element pair (stable).

Simulations :: structure results

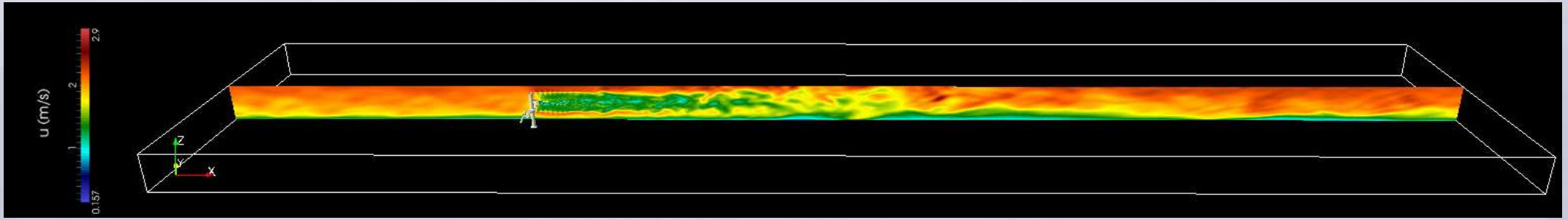
- Structure generates large wake of its own (250m long)
- Crossbeam in particular creates large wake
- Substantial turbulence produced by structure (vortex shedding clearly visible)
- Strongly 3D effect - varies with height above seabed

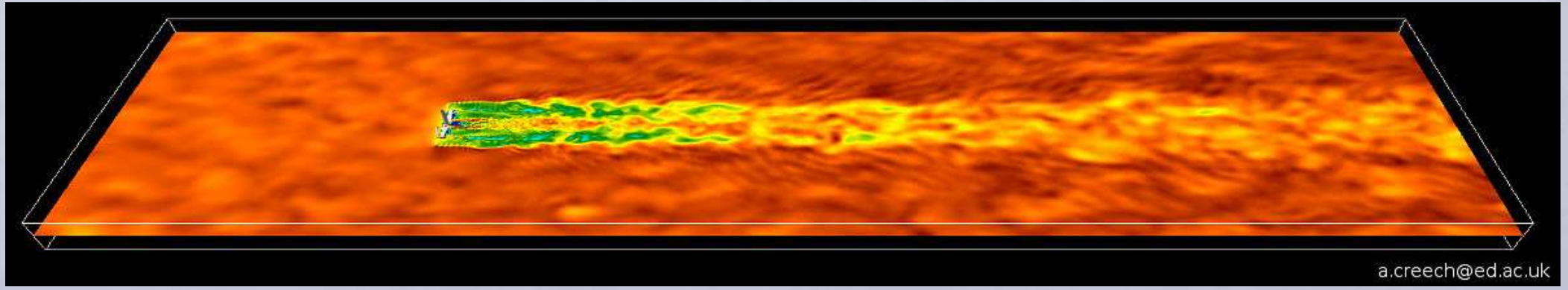




Simulations :: structure+rotor results (1)

- Wake from rotors clearly extends beyond 750m
- Little interaction apparent between rotors
- Turbulence interaction with seabed far downstream





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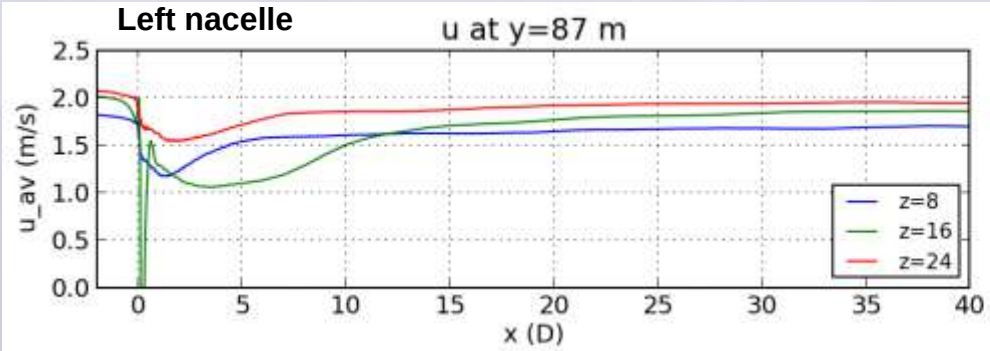
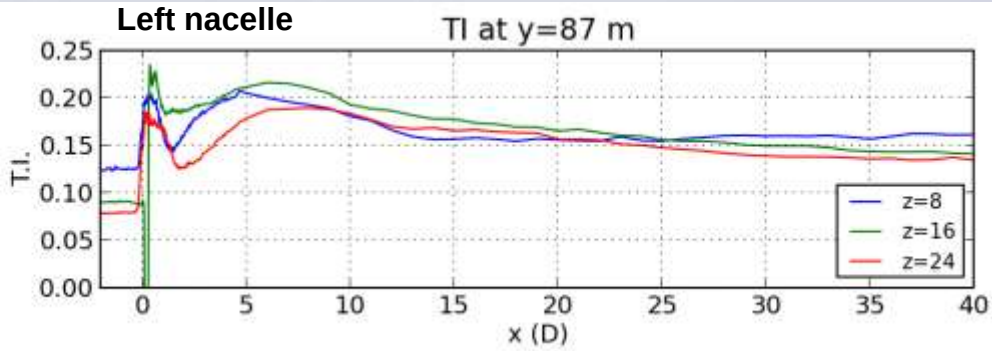
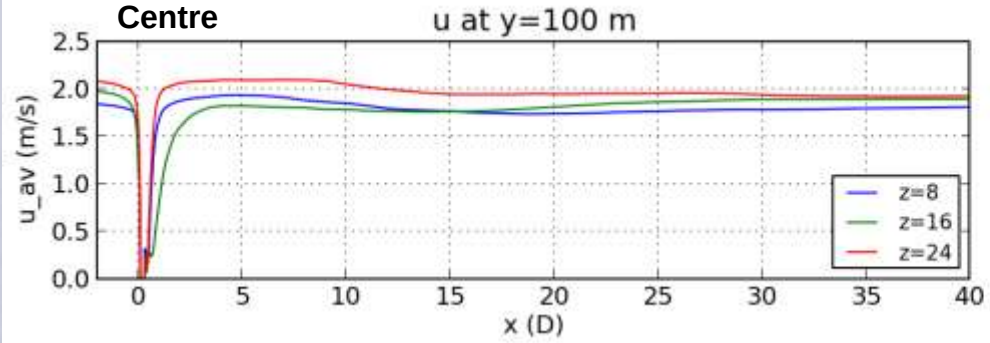
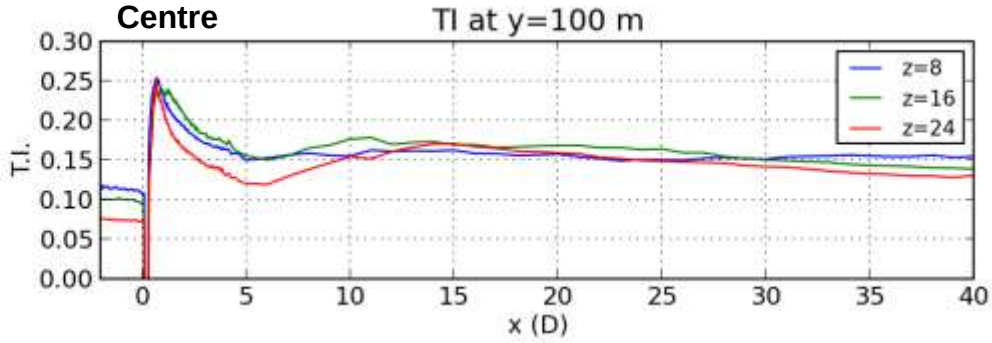
Simulations :: structure+rotor results (2)

- Streamwise plots for speed (u) and turbulence intensity (TI)
- At nacelle (y=87m) and tower (y=100m)
- Much longer wake deficit recovery – 30D (480m)
- Turbulence takes longer decay to take than structure (>750m)
- Spike in TI followed by second peak

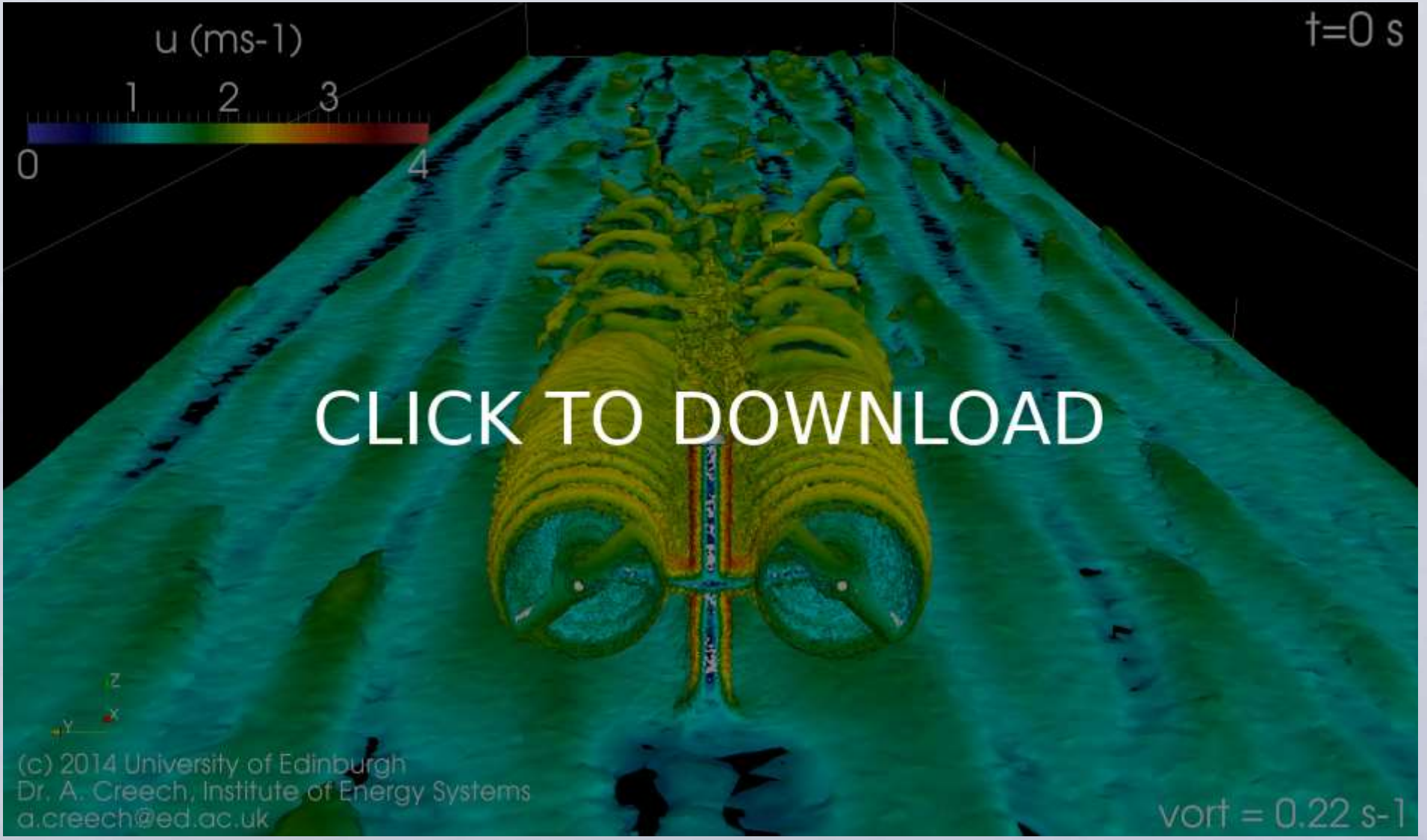








Simulations :: results (video)



Turbine modelling :: conclusions

- The structure of the turbine generates substantial turbulence
  - Turbulence decays quickly
- Wake from rotors similar peak intensity, but persists longer
  - Structure of turbulence important
- Resolving turbine structure in CFD simulations is resource intensive (FLOWBEC → 8.5 TB data)

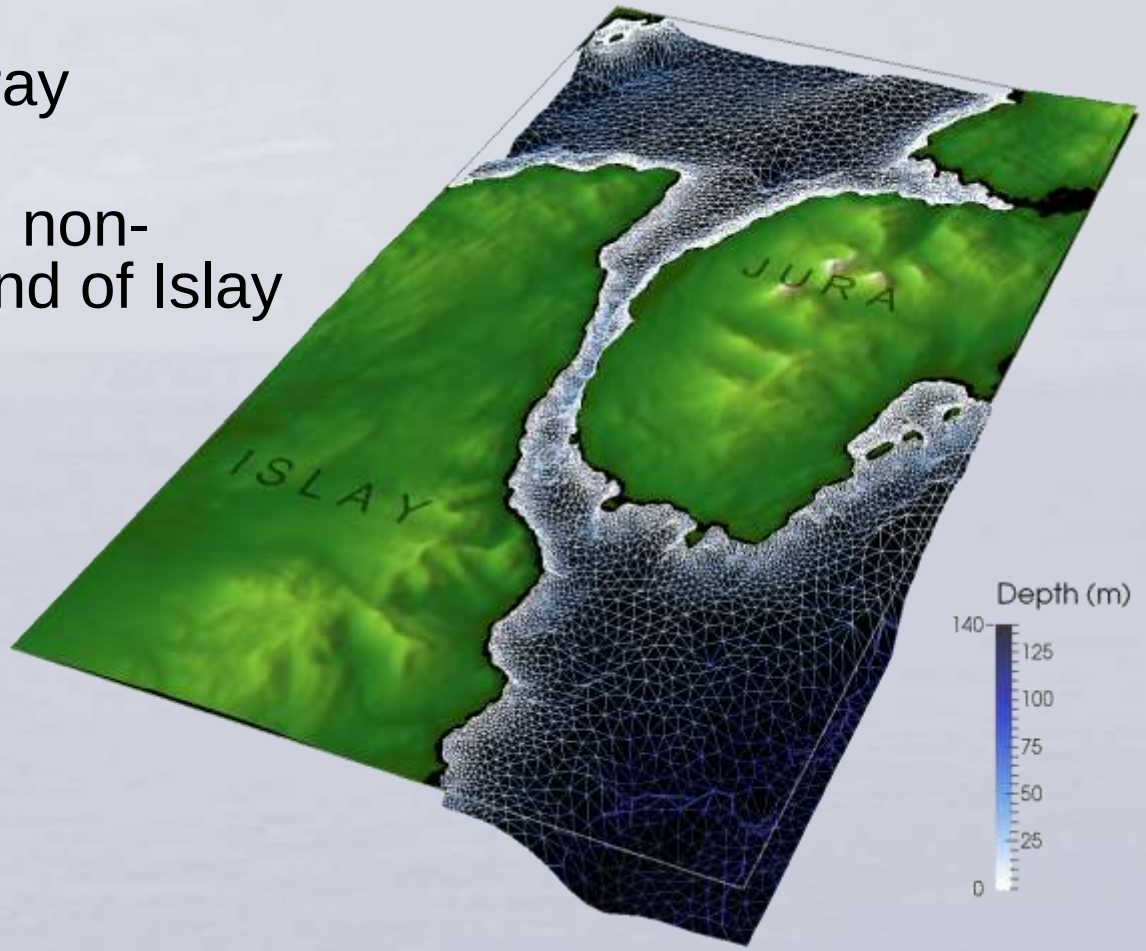
Real-world evidence

- Surface wake from SeaGen at Strangford - Bing maps

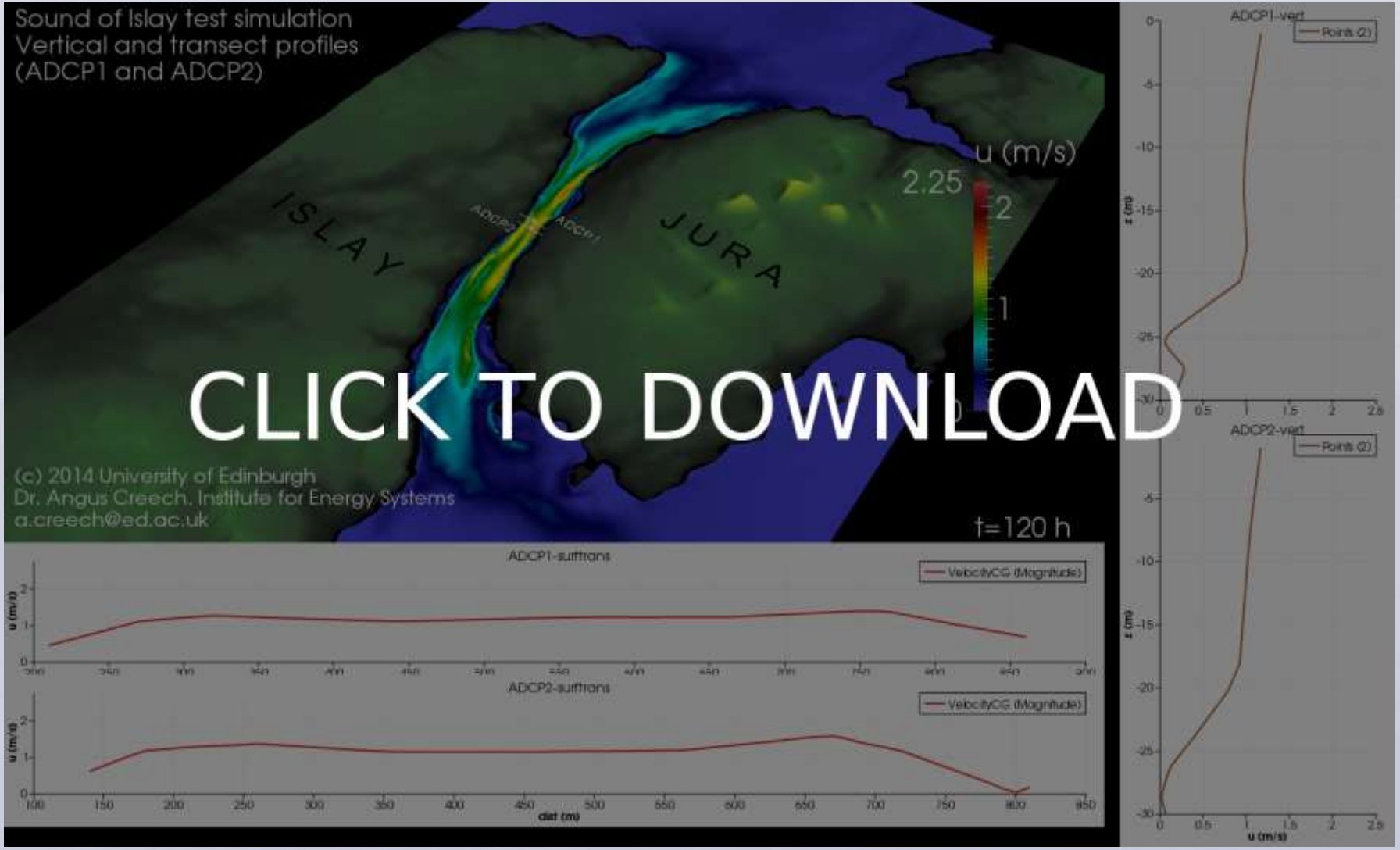
Coastal modelling: Sound of Islay

Sound of Islay:: overview

- NERC IAA funded, support from Scottish Power
- Proposed site for tidal array
- High fidelity, unstructured non-hydrostatic model of Sound of Islay
- Bathymetry from UKHO
- Anisotropic turbulence modelling
- A work in progress (!)



Initial results :: video (1)



Initial results :: video (2)

- Vertical velocity slice through main part of channel
- High vertical shear
- Extremely non-hydrostatic

Conclusions

- Flow is extremely turbulent, with strong vertical shear
- Large-scale turbulence features (>250 m)
- Flow reversal throughout water column
- Strongly influenced by both bathymetry and coastline
- Depth-integrated and hydrostatic models – applicability in highly energetic tidal enviroments?
- Implications for tidal turbine reliability and performance?

Any questions?