Opportunities for the UK in Tidal Energy

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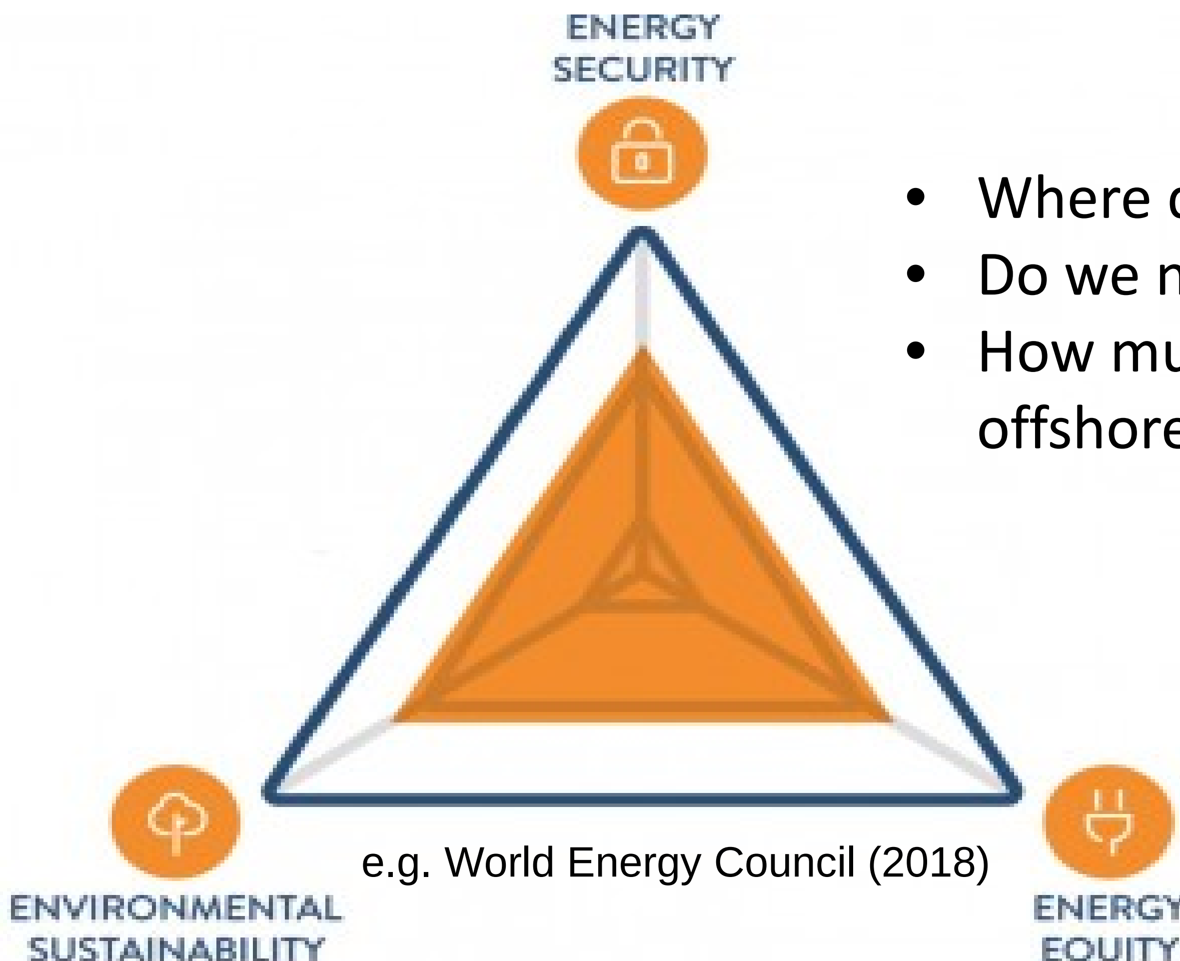
Outline

- The Energy Trilemma
- What is Offshore/Marine Renewable Energy?
- What contribution could tides make to UK renewable energy?
- The benefits of computer tidal models
- Estimation of large scale resource and environmental impacts
- What are the outstanding challenges? The way forward – politics, economics and engineering

The Energy Trilemma



(Accessibility and affordability)

e.g. World Energy Council (2018)

- Where does UK stand? AAA
- Do we need renewable energy?
- How much of a role is there offshore/marine energy?

Look at GridCarbon smartphone app to see how we are doing

Offshore/Marine Renewable Energy

- The EU's Renewable Energy Directive (2009/28/EC) sets a binding target of 20% final energy consumption from renewable sources by 2020

- UK target is 15% of all energy from renewables by 2020 – this breaks down to 30% electricity, 12% heat and 10% transport fuels – we may achieve first but are likely to miss the other two

- What about wave power? – large potential but early stage for significant exploitation (despite publicity for Salter's Ducks in 1970's). Promising technology has failed e.g. Pelamis

- Wind Power – 21 GW deployed capacity (8GW offshore, generating 8% UK electricity) seen as producing 15% of UK electricity by 2020
  In 2009 the UK became the leading country for offshore installed wind capacity

- Tidal Stream – 5% (SDC,2007) ~ 7GW capacity

- Tidal Barrages – 15% (Burrows et al 2009) – NW England ~ 5% (comparable to the Severn Barrage); Mersey Barrage ~ 1 TWh ~ 0.3% ~ 210 Wind Turbines

Ancient tide mills e.g. **Nendrum Monastery, Strangford Lough** (founded 619-621 AD)

Artist's impression of early medieval water mill
– estimated power 7-8hp ~ 5-6kW

SeaGen 1.2MW 2008-2017

Tidal energy is a form of hydro-power
Exploitation of this goes back a long way, at least to irrigation in Mesopotamia and ancient Egypt (6th century BC)
The water-mill was probably invented by the ancient Greeks c.300 BC

Tide Mills, East Sussex

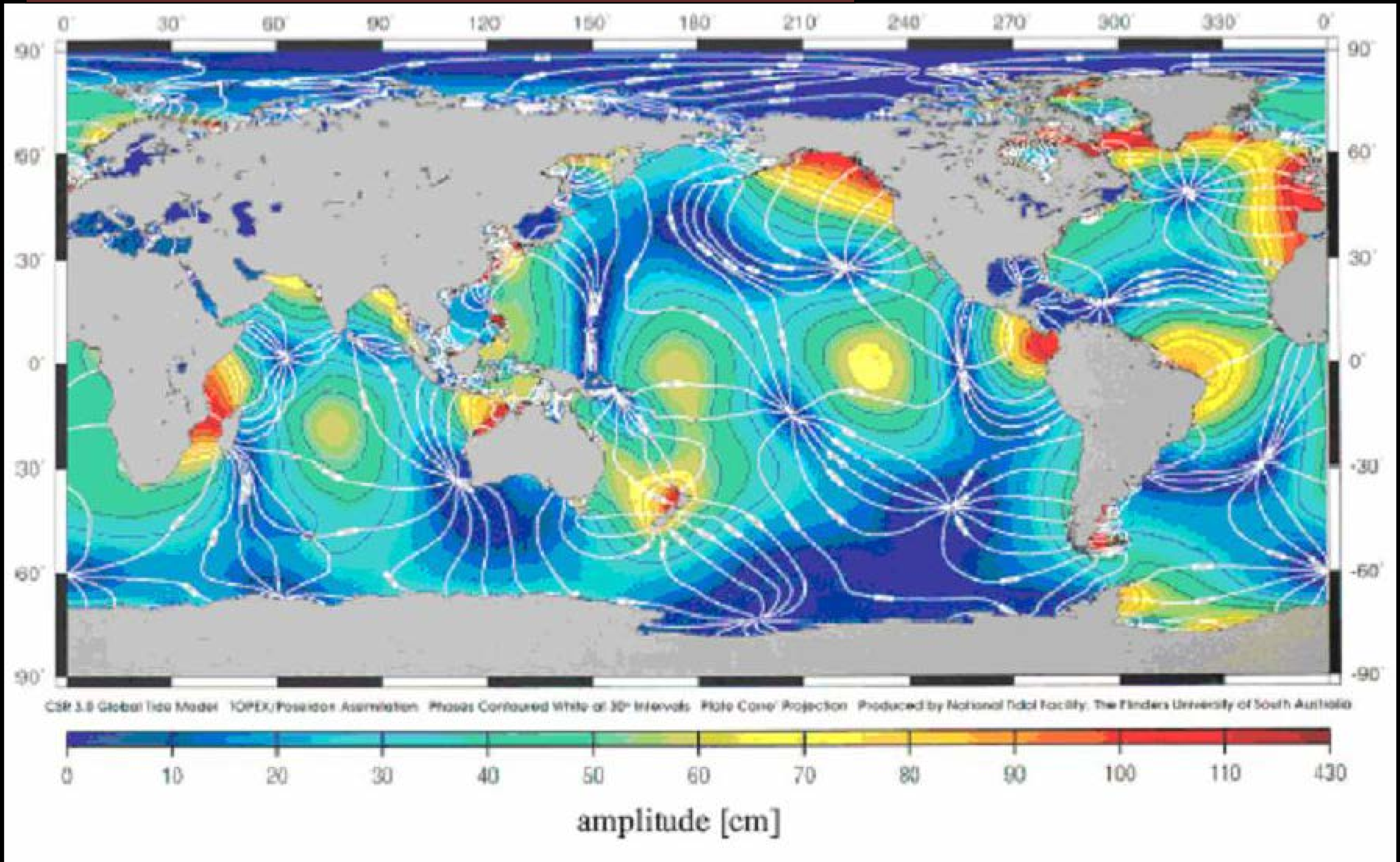

Remains of mill race sluice – left: seaward side, right: millpond side

Ancient tide mills were used for grinding grain

Where does tidal energy come from?

- Refer to tidal theory, analysis and predictions as described by earlier speakers
- Tide-generating forces act in the deep ocean – gravitational attraction of moon and sun, modified by self-attraction and loading, and dynamical response of water
- Tides are driven on the shelf by co-oscillation with the ocean
- Tides are amplified as they move from deep ocean (5000m) to shelf seas (200m) and dissipated in shallow coastal waters (10m)
- In some locations there is near-resonance, where the quarter wavelength of the main tidal wave (semi-diurnal lunar tide, M_2) matches the distance to the reflecting boundary e.g. in Bristol Channel/Severn Estuary, Bay of St Malo (English Channel/Channel Islands), Hudson’s Bay & Bay of Fundy (Canada)
- Tides are large in the NE Atlantic near the UK – UK has about 10% of global tidal energy resource and 50% of European resource and good access to markets

Global M2 Tidal Amplitude



Tidal energy flux from observations

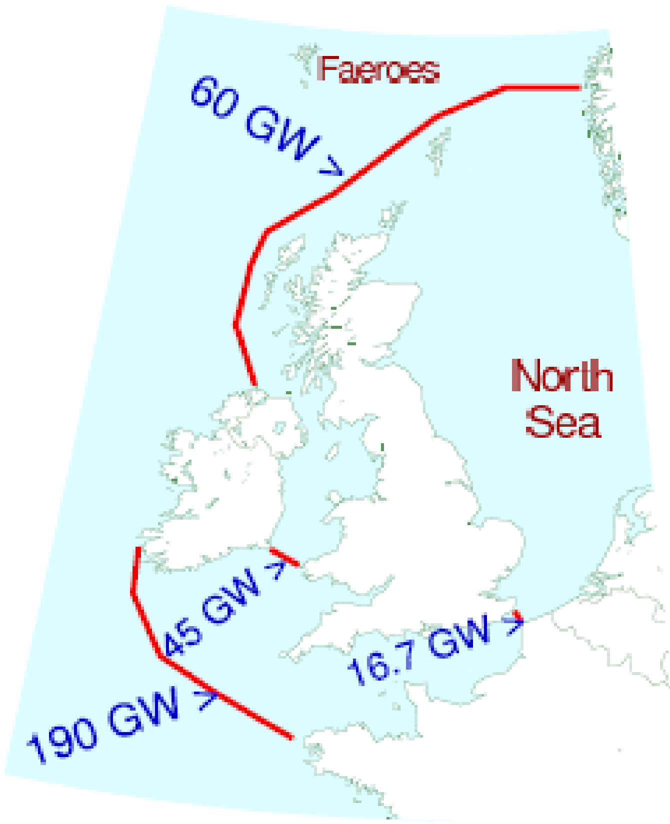


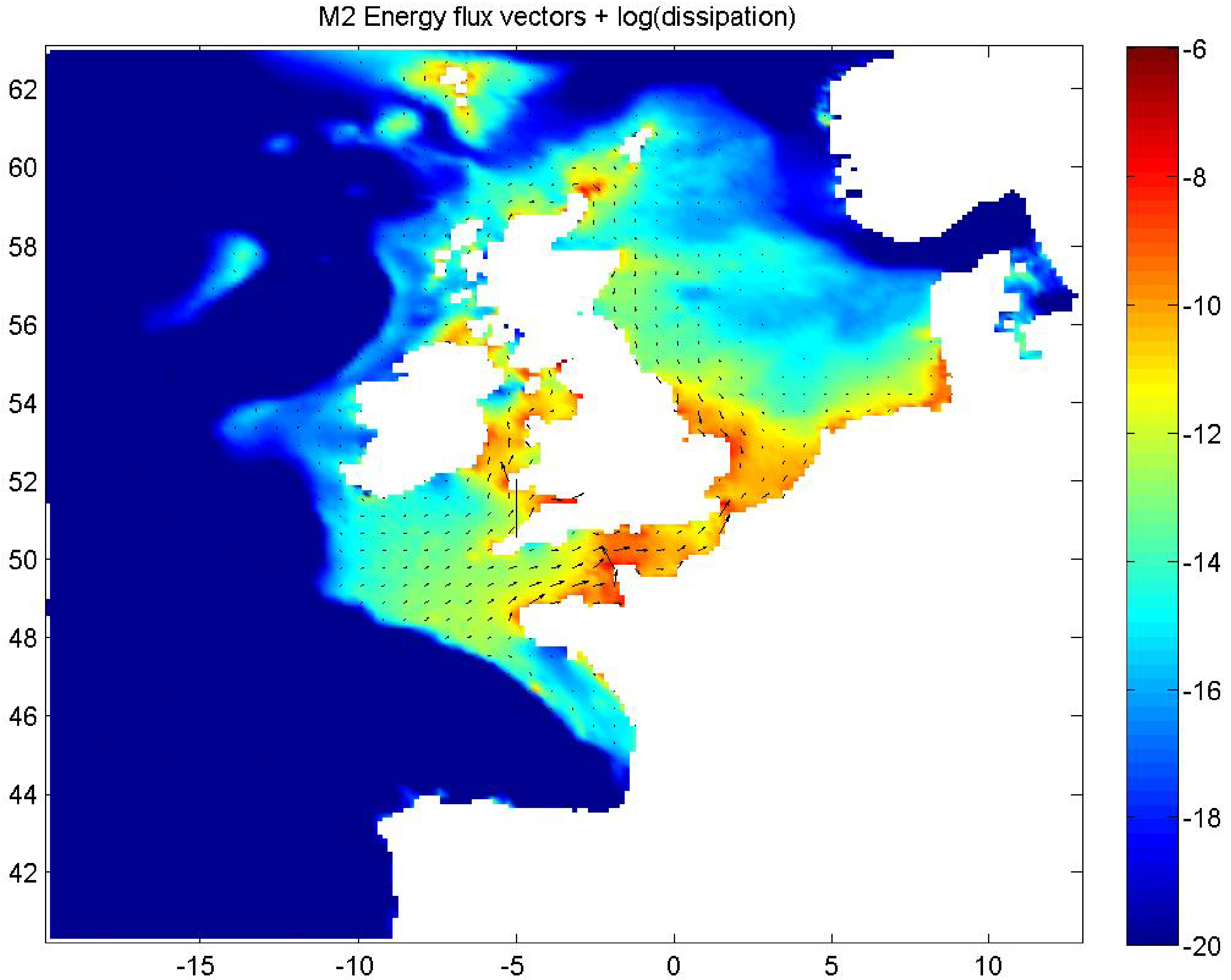
Figure G.4. Average tidal powers measured by Cartwright et al. (1980).

Figure from MacKay (2009)

'Sustainable Energy- without the hot air'

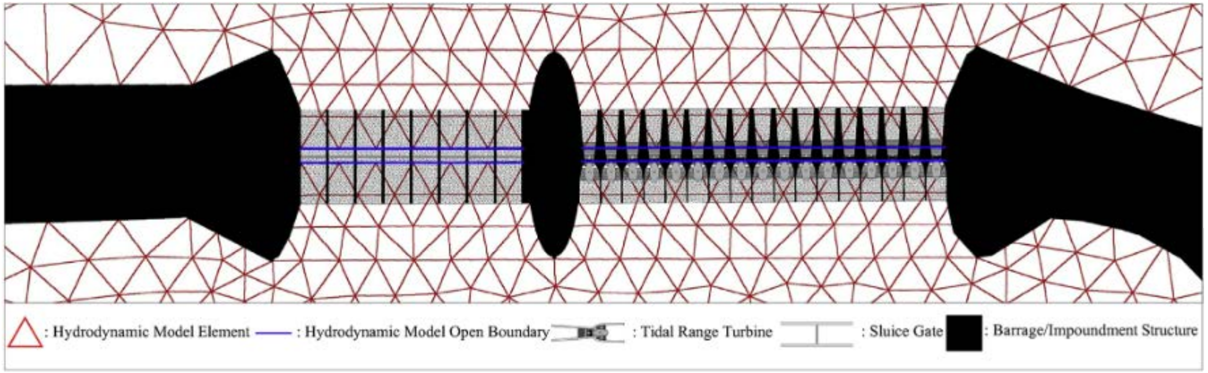
The calculations of energy flux in Cartwright et al (1980) were from bottom pressure and current meter measurements

Energy flux from 12km tidal model



How to build a tidal model

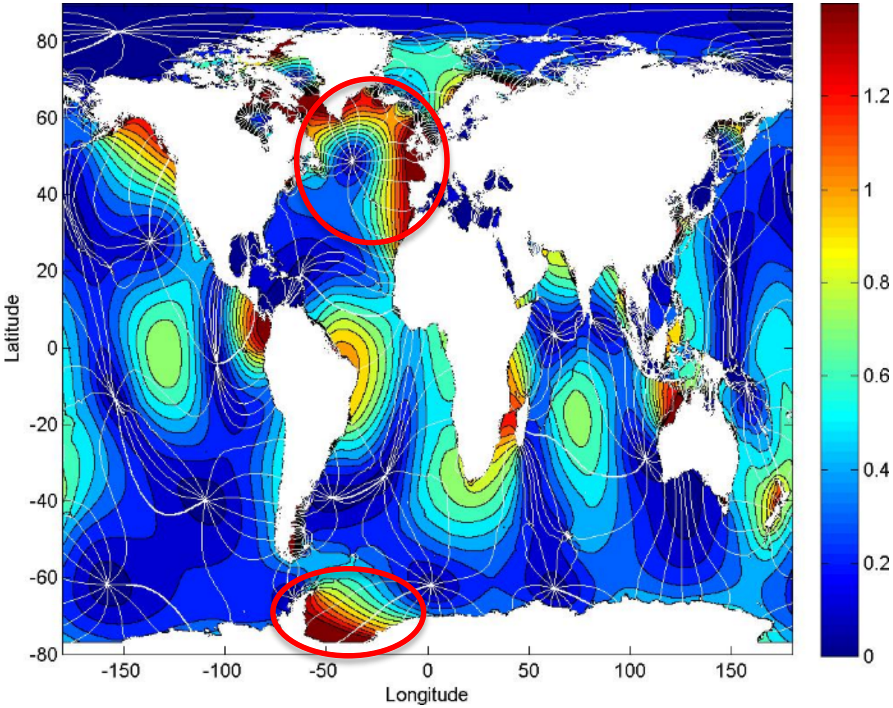
- Divide up sea area into boxes (which may all be the same size or vary)
- Supply bathymetry, boundary conditions, initial conditions and external forcing in each box
- Solve Newton's equations of motion (in the form of the Navier-Stokes equations for incompressible, viscous fluids) in each box*
- We may apply the tide-generating forces directly to the box (for global tidal model) or assume the tides are generated in the deep ocean and applied at the ocean boundary (for a regional model)



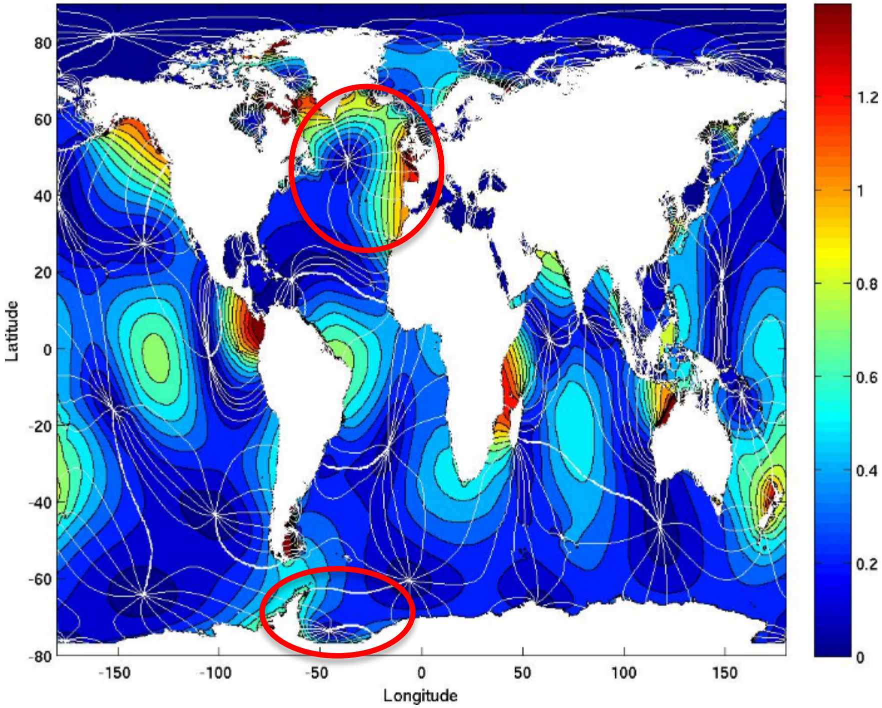
Arrangement of hydrodynamic model mesh (in plan view) around caissons, turbines and sluices for a tidal barrage or lagoon (from Angeloudis et al., 2016)

* this requires some assumptions about the behaviour of sea water and also the approximation of the equations into finite difference, finite volume or finite element forms for numerical solution

Effect of bathymetry in a global model



M2 co-tidal chart obtained with GEBCO bathymetry

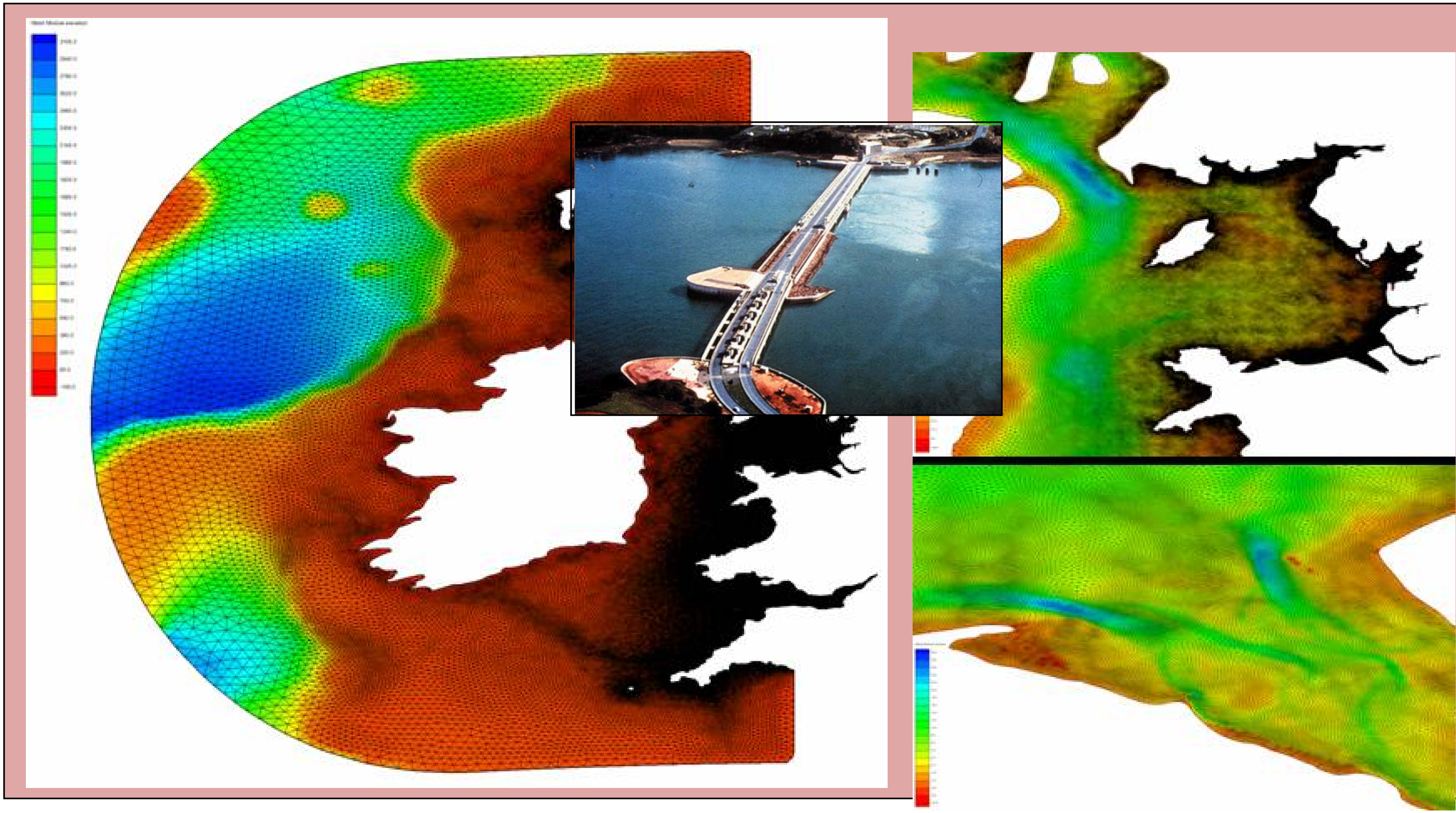


More accurate M2 co-tidal chart obtained after updating the model bathymetry around Antarctica using the BedMap2 data set, including effects of ice

Note change in tide in Weddell Sea and reduction in amplitude in North Atlantic

https://www.fast4nl.nl/ProjectDescription.html

Tidal Power Potential of Eastern Irish Sea (Liverpool University and NOC, Joule Project, 2006-2009)



Tidal barrages in the estuaries of the North West of UK could meet half the region’s present electricity needs.

Grid resolution varies from 15km at the ocean boundary to ~50m in estuaries of interest: Severn, Dee, Mersey, Ribble, Morecambe Bay and Solway Firth

Using numerical models for tidal resource and impact estimation

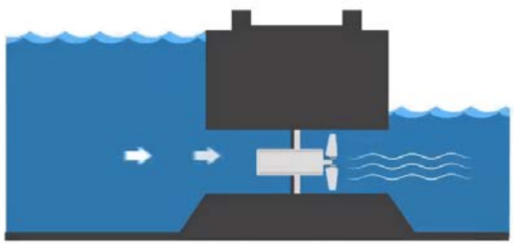
Types of model:

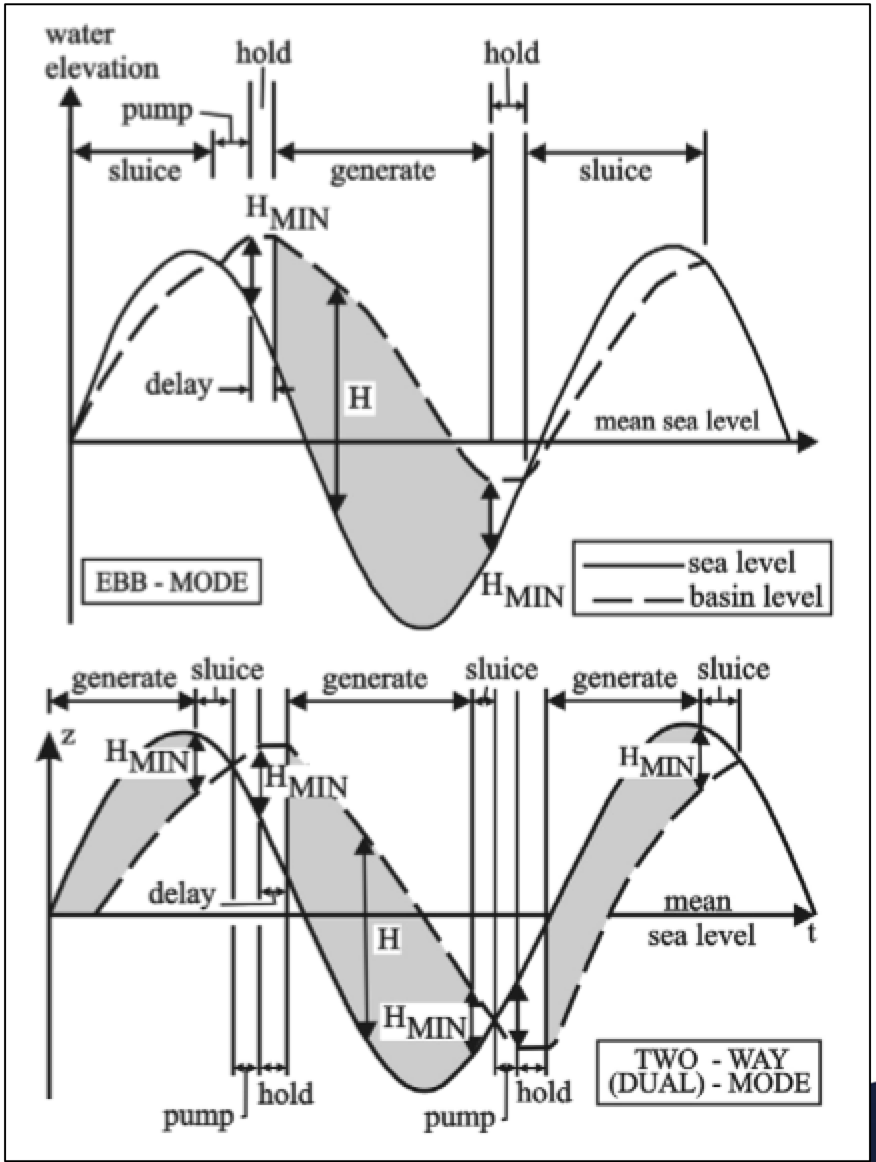
- 0D – uses simplified equations for flow through a tidal turbine
- 1D – cross-sectionally-averaged equations e.g. for rivers
- 2D – (usually) depth-averaged – often used in global models
- 3D – full 3D equations, allows for variation in flow through the vertical, effect of salinity, sediment in estuaries

Global versus regional models:

- For global models we include the effects of the tide generating forces, self-attraction and loading
- For regional models in shelf seas we only need to provide the tides at the open boundary, often using a limited number of tidal constituents of the deep ocean tide, taken from global tidal models and satellite altimetry
- We need to take the boundary sufficiently far offshore if we have tidal resonances (enhanced amplification of the tide) within the model (e.g. Bristol Channel, Channel Islands, Bay of Fundy, Hudson's Bay)

0D model of a tidal barrage





Global Tidal Stream Energy Resources

UK Tidal Energy Resources

Figure 3 UK tidal range resource

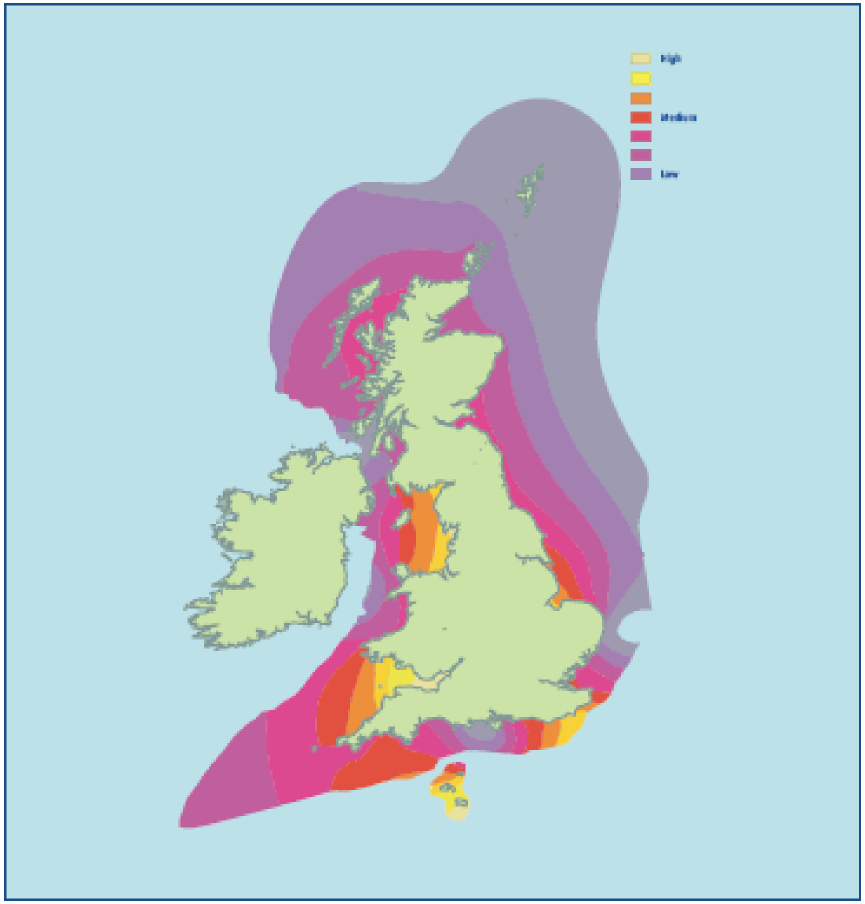
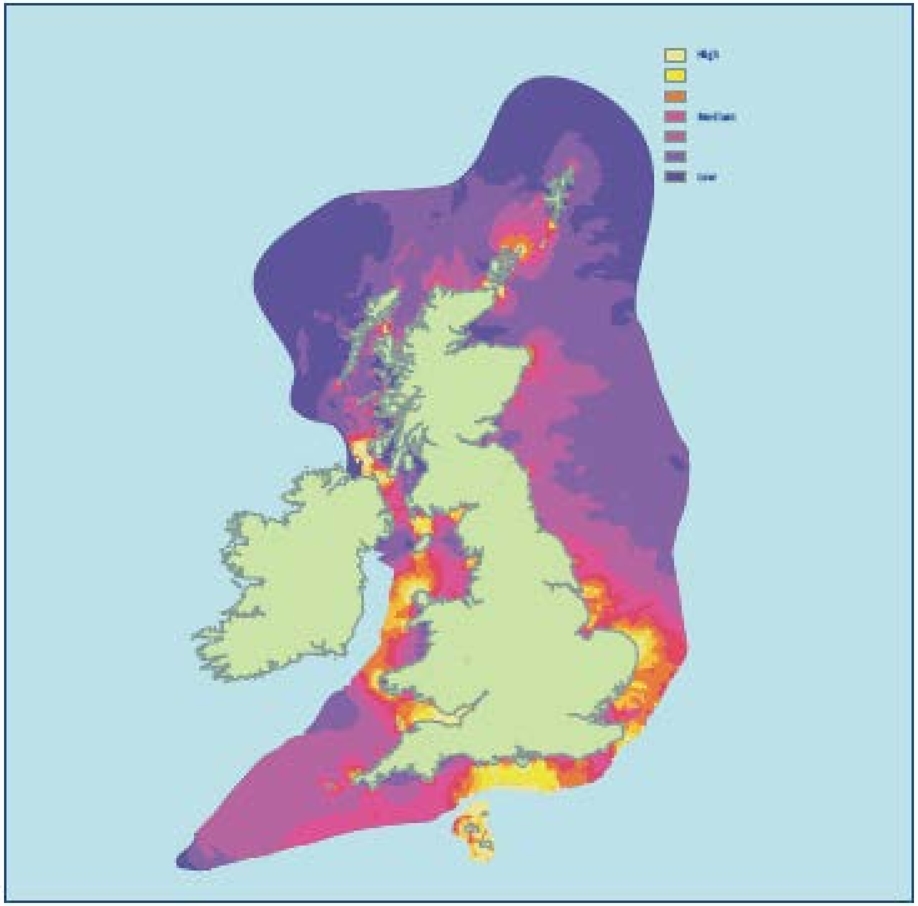
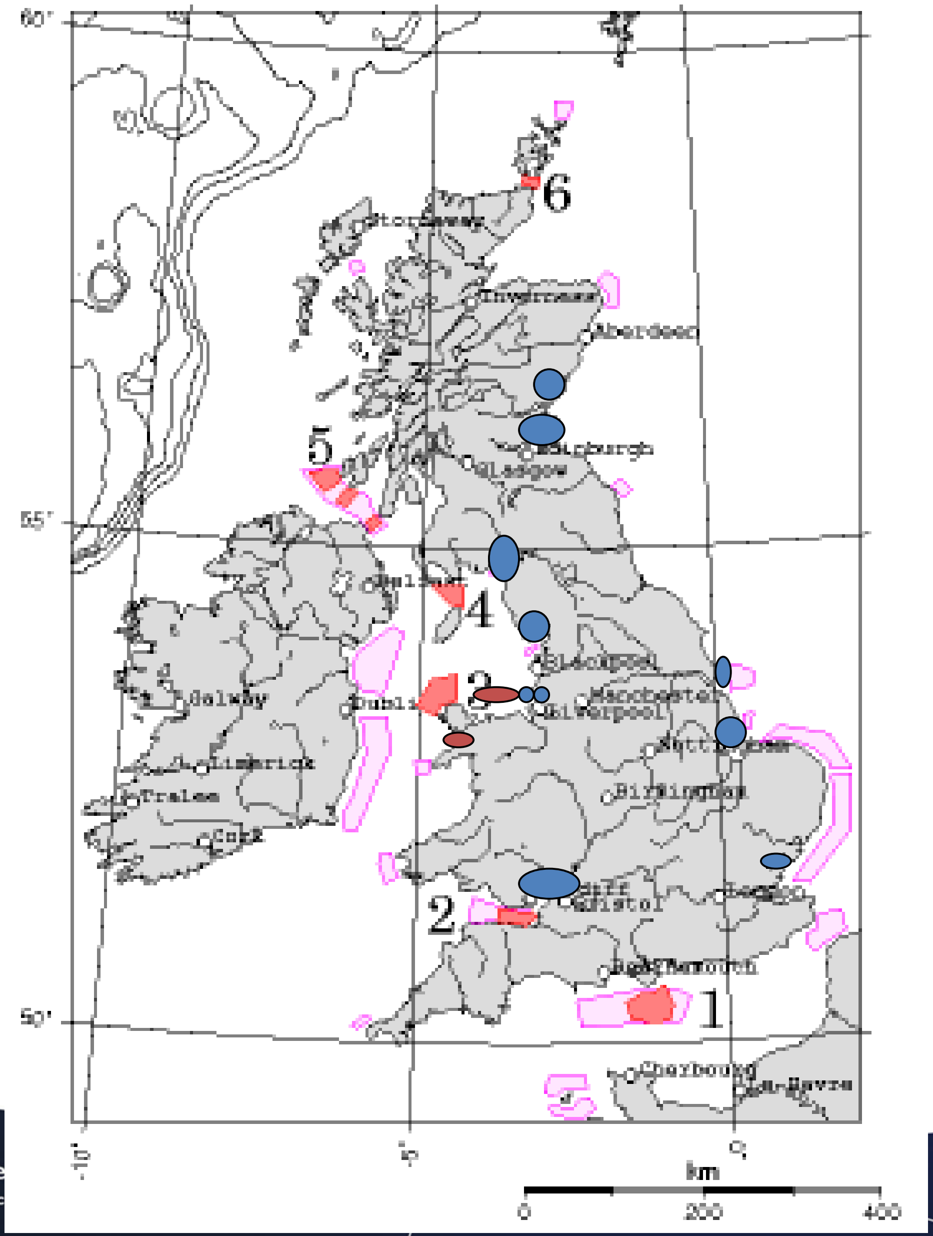


Figure 2 UK tidal stream resource



Tidal Energy Resources



From MacKay (2009)

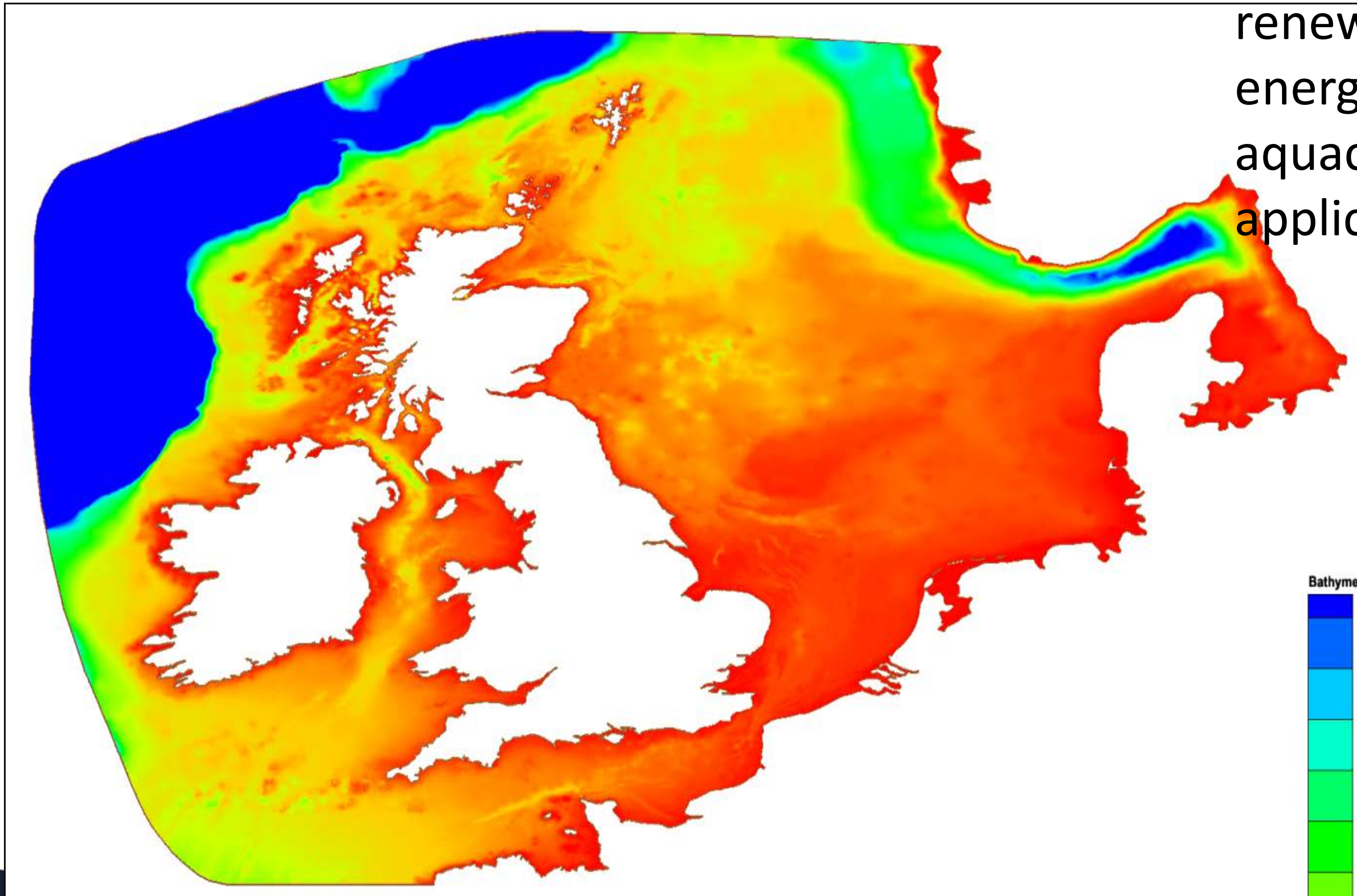
'Sustainable Energy- without the hot air'

Red/pink - Regions with peak currents exceeding 1m/s

Estuary barrage

Coastal lagoon

Scottish Shelf Model: FVCOM unstructured grid, developed for Scottish Government for marine renewable energy and aquaculture applications



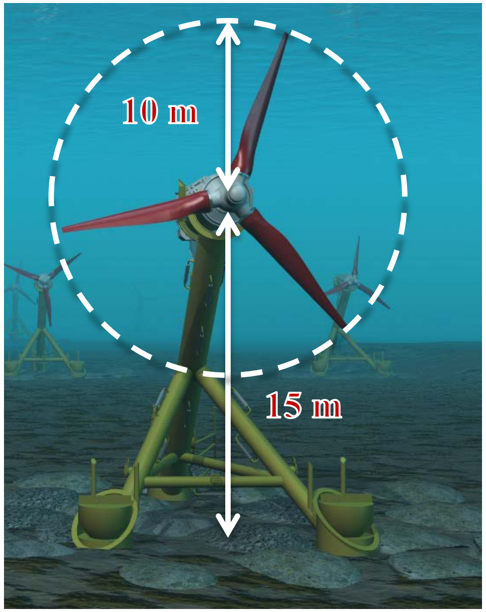
aquaculture

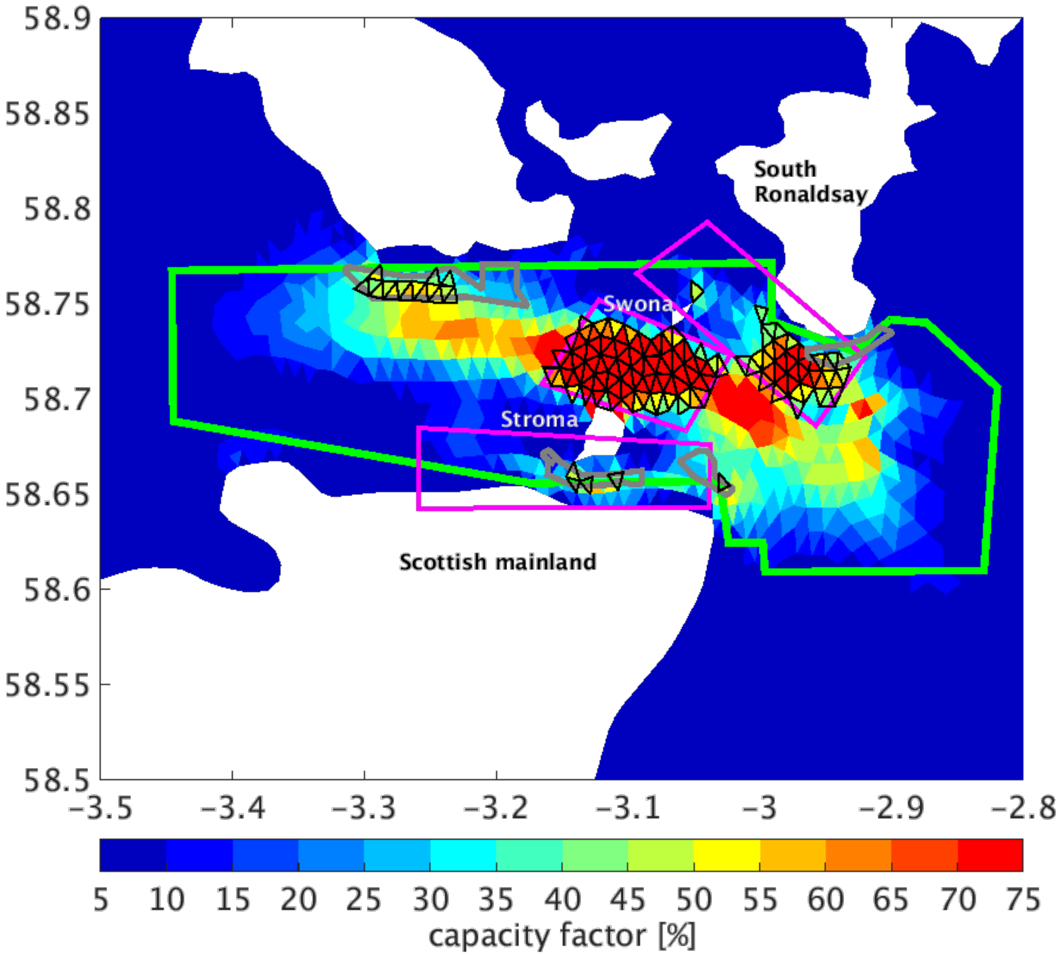
Pentland Firth - tidal stream turbines large-scale array scenario

Minimum water depth:
27.5 m

Minimum spacing between turbines:
lateral 3 device widths,
downstream 15 device widths

Minimum capacity factor:
40%





number of turbines ≈ 2800

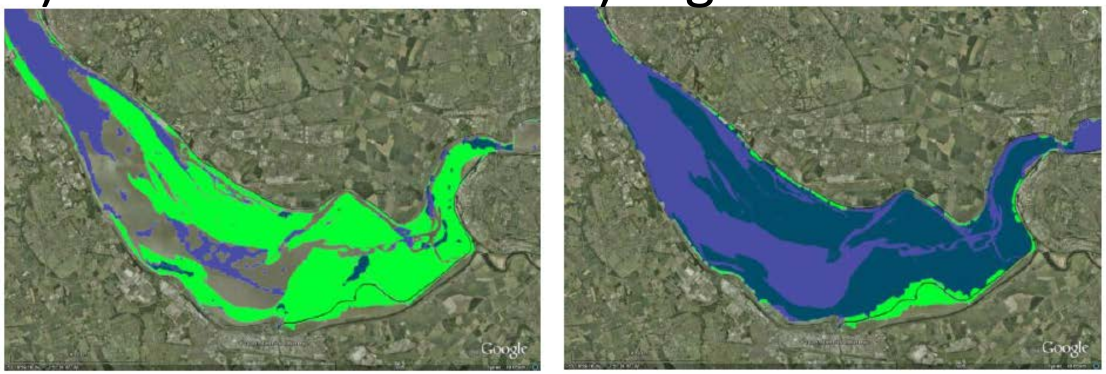
Sustainable use of natural resources

How will barrages, turbines, wind farms and other energy extraction devices affect the flow, the sediment transport, habitats and ecology of our seas?

There may be long term, large area changes in tidal distribution due to changes in the tidal system.

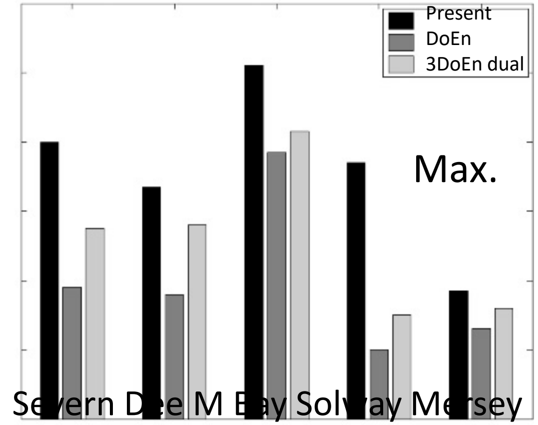
Potential impact of a Mersey barrage on intertidal habitats

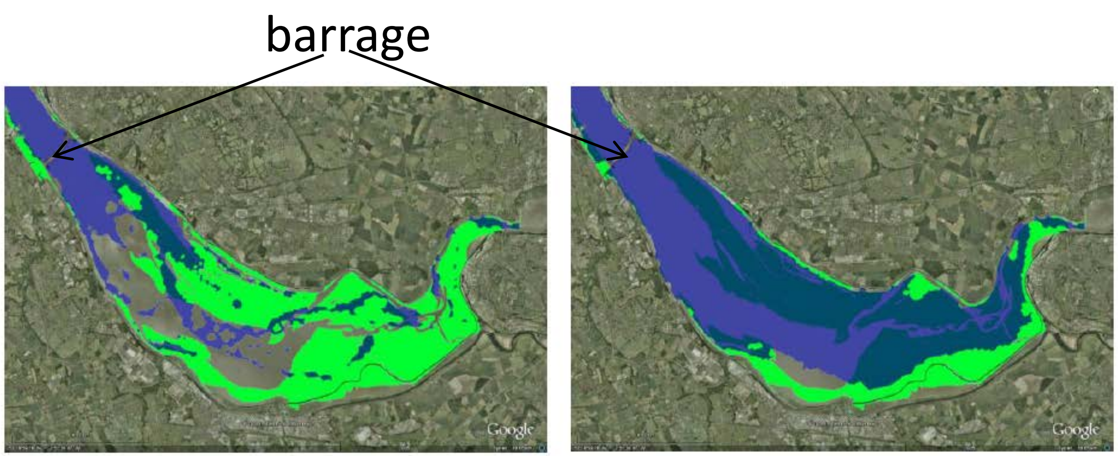
a) Low water b) High water



Mudflats in Mersey (green) with undisturbed spring tide

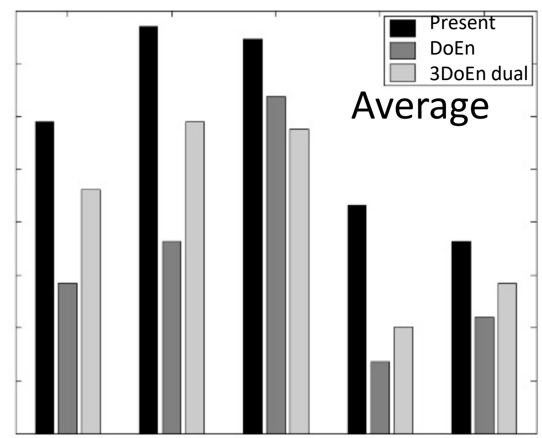
Intertidal area





Mudflats in Mersey (green) with DoEn ebb-mode spring tide

(c/o Ian Walkington)



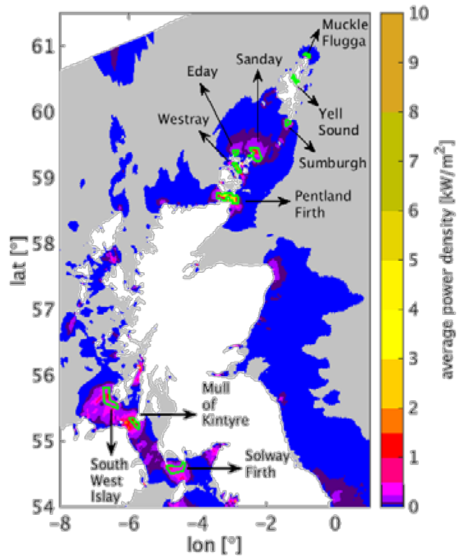
Wolf et al. (2009)

SUMMARY: Predicting future changes in the physical marine environment in 2050 - large tidal stream turbine arrays and climate change effects

EcoWatt2050

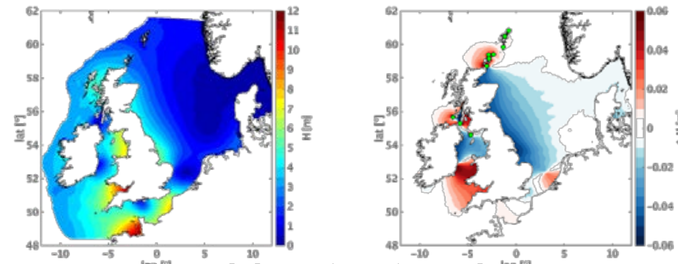
How can large arrays of tidal stream energy devices affect ocean hydrodynamics?

Will the **energy extraction** by maximum deployment of marine renewables ameliorate or exacerbate the predicted effects of **climate change**?

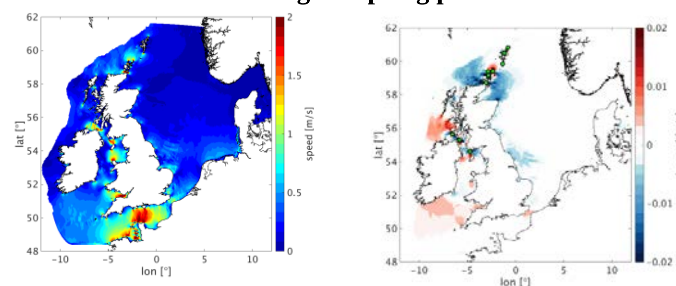


Energy Extraction: Impacts on tides

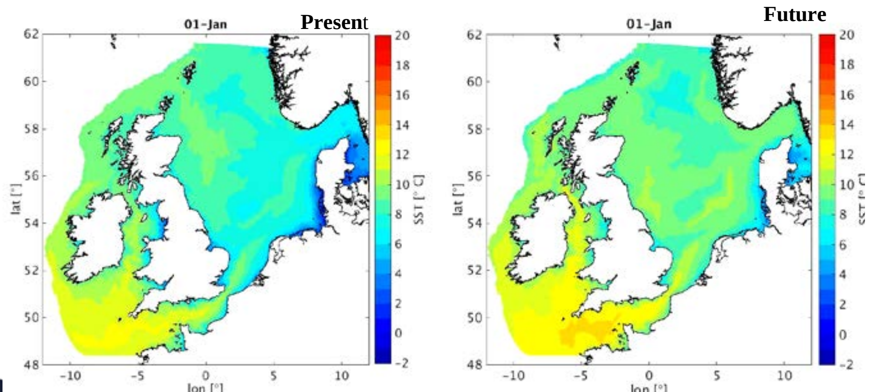
Baseline and change spring peak tidal range.



Baseline and change in spring peak currents.

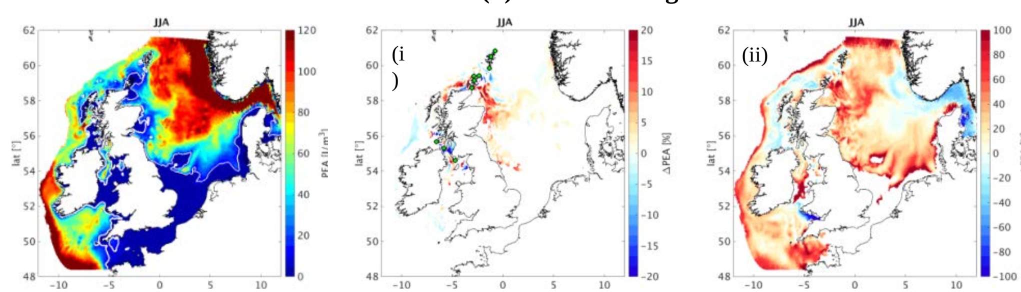


Climate Change: A typical annual cycle of the present and future hydrodynamics was reproduced by the Scottish Shelf Model



CC+EE Impacts on summer stratification

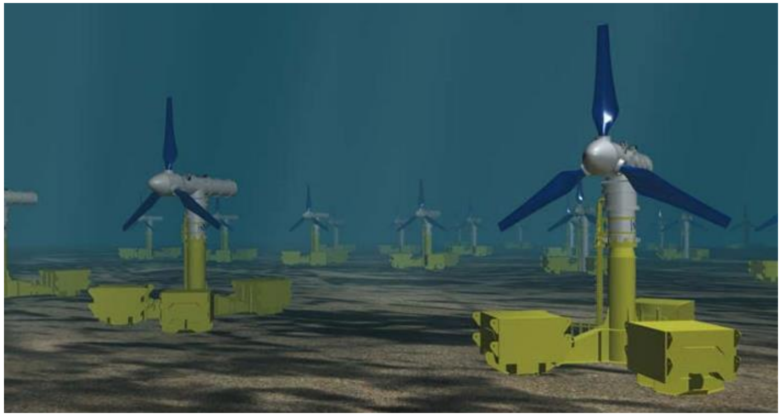
Baseline and % change in Potential Energy Anomaly (PEA) due to (i) energy extraction and (ii) climate change.



Climate change and tidal energy extraction both act in the same direction in terms of increasing stratification, however the changes due to the climate change scenario are an order of magnitude larger.

Tidal installations

Tidal Stream Energy Converters (TECS): horizontal axis turbines, vertical axis turbines, oscillating hydrofoils, venturi devices, Archimedes screws and tidal kites



MeyGen: Inner Sound, Pentland Firth, Dec 2016

The first **0.5MW** utility-scale system of **Minesto**'s patented **Deep Green** technology has been commissioned at the Holyhead Deep site off the coast of North Wales, (October, 2018)

Pros and Cons of Use of Numerical Models for Tidal Energy Resource and Impact Estimation

- We have confidence in state-of-the-art models for present day oceanographic conditions (provided they are properly validated)

- We can use models to test scenarios before any installation is built, especially for large arrays of tidal, wave and offshore wind, including effects of their combined operation (but we need good methods of implementing devices and ground truth to validate these – generally only lab experiments are available)

- It is important to explore the model sensitivity/parameter space e.g. for friction, which is a secondary force dependent on the model solution and is still generally not externally specified from seabed conditions (grain size, bedforms etc.)

- Models can be used to interpolate and extrapolate sparse observations and clarify processes and mechanisms, pinpointing where key observations should be made

Challenges for the UK

- Climate Change Act (2008) and the Renewables Obligation Order (2009, 2015) – UK needs to reduce GHG emissions and increase production of renewable energy

- 2016/17: Electricity on track but heat and transport falling behind

- Tidal energy could produce up to 20% of present UK electricity demand – **how much tidal stream resource is realisable**? Should we revisit **tidal barrages** (especially the Severn and the Mersey)? **What about tidal lagoons?**

- How to deal with the **intermittency** of wind, wave and tidal energy – **energy storage** and **alternative fast response systems**

- **The final obstacles: Up-front costs and environmental impacts, perception of the urgency of the need to de-carbonise**

Thanks for your attention
Any questions?

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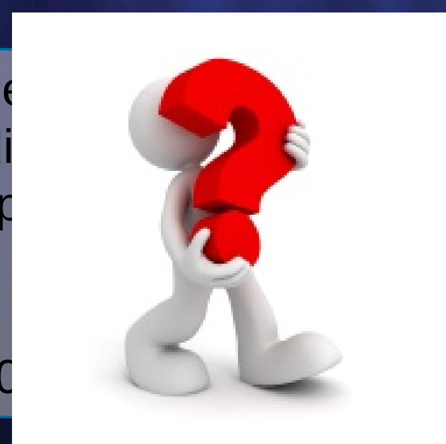

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