Can tidal stream turbines change the tides in the Pentland Firth?

And is there an acceptable limit?

Rory O'Hara Murray

The Scottish Government

marinescotland
science

Plan Options for Offshore Wind and Marine Renewable Energy and Planned developments in Scotland

Map is indicative. An interactive versi
map can be found on NMPi. Upd
sets will be added to NMPi when

Detail Key

Offshore Wind and Marine Renewable Energy

Key:

- 12 Nautical Miles

Sectoral Marine Plan Options

- Offshore Wind Plan Options
- Wave Plan Options
- Tidal Plan Options

Saltire Prize Identified Areas

- Tidal
- Wave

Planned Developments

- Scottish Territorial Waters offshore wind sites
- Round 3 offshore wind zones
- Test and Pilot offshore wind sites
- Robin Rigg offshore wind demonstrator
- Wave leases (The Crown Estate leasing round)
- Tidal Leases (The Crown Estate leasing round)

Plan Options for Offshore Wind and Marine Renewable Energy and Planned developments in Scotland

Detail Key

Offshore Wind and Marine Renewable Energy

Key:

- 12 Nautical Miles

Sectoral Marine Plan Options

- Offshore Wind Plan Options
- Wave Plan Options
- Tidal Plan Options

Saltire Prize Identified Areas

- Tidal
- Wave

Planned Developments

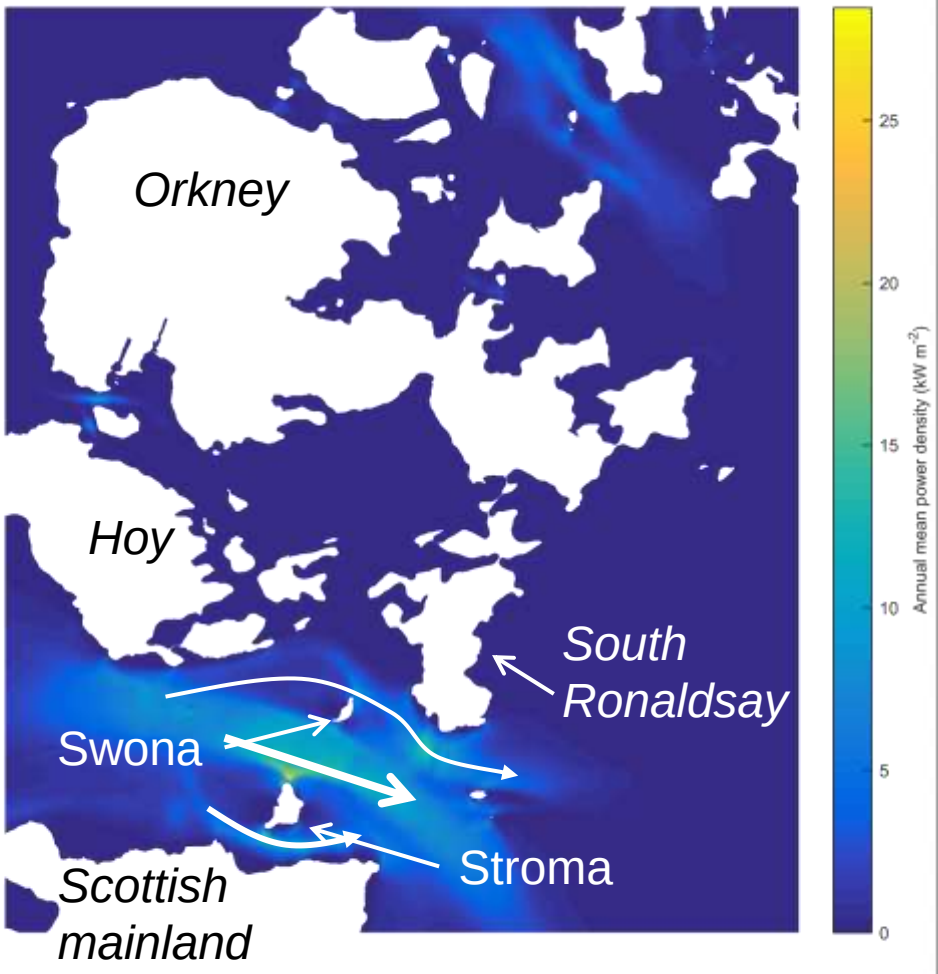
- Scottish Territorial Waters offshore wind sites
- Round 3 offshore wind zones
- Test and Pilot offshore wind sites
- Robin Rigg offshore wind demonstrator
- Wave leases (The Crown Estate leasing round)
- Tidal Leases (The Crown Estate leasing round)

4 x lease areas in the Pentland Firth region

Total nominal leased capacity of 800 MW

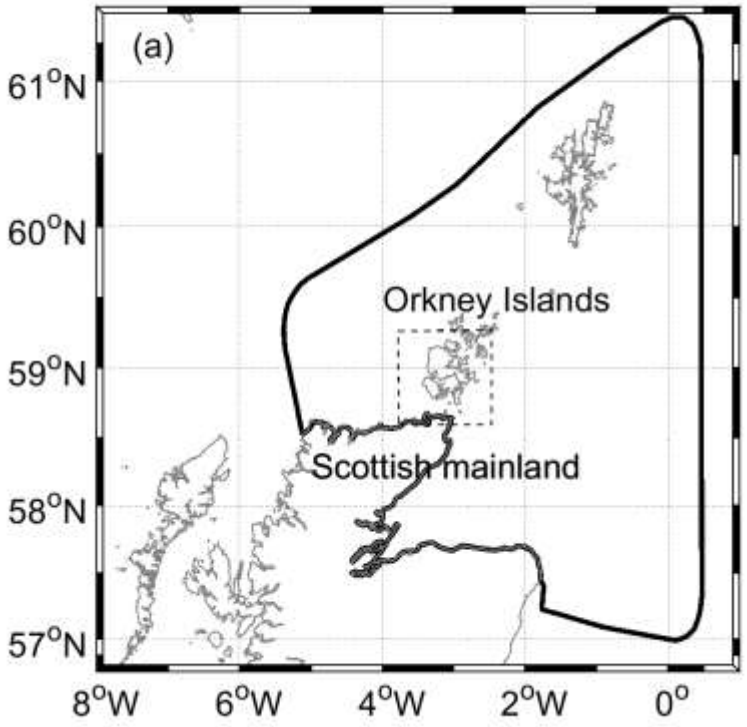
Pentland Firth

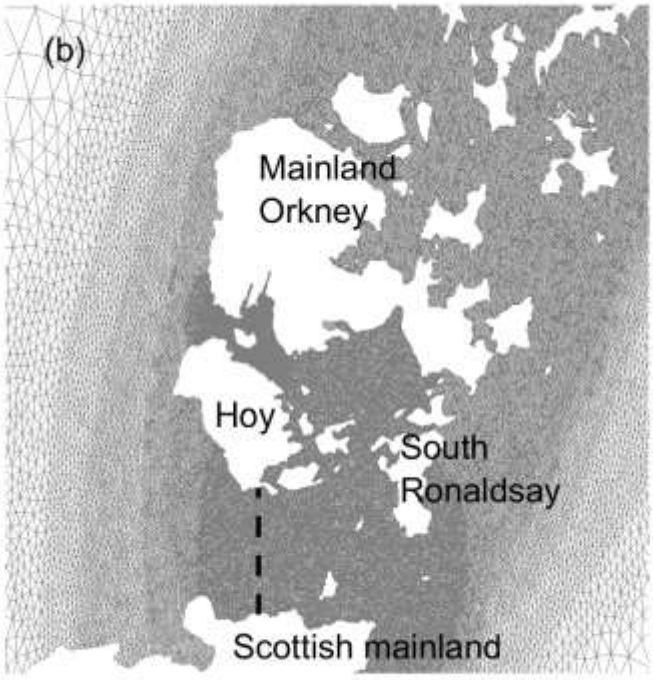
- **Pentland Firth is made up of three channels**
  - Most flow in main channel
- **Potential for flow to be diverted if all three channels are not utilised**
- **Hard to estimate how much power can be extracted from the flow**
- **O'Hara Murray and Gallego (2017) modelled spring-neap cycle:**
  - 18.4 GW maximum
  - 5.3 GW temporal mean
  - 2.2 – 8.3 GW daily mean
- **How much power can *realistically* be extracted ?**
- **How might the tides change ?**



Pentland Firth and Orkney Waters Model

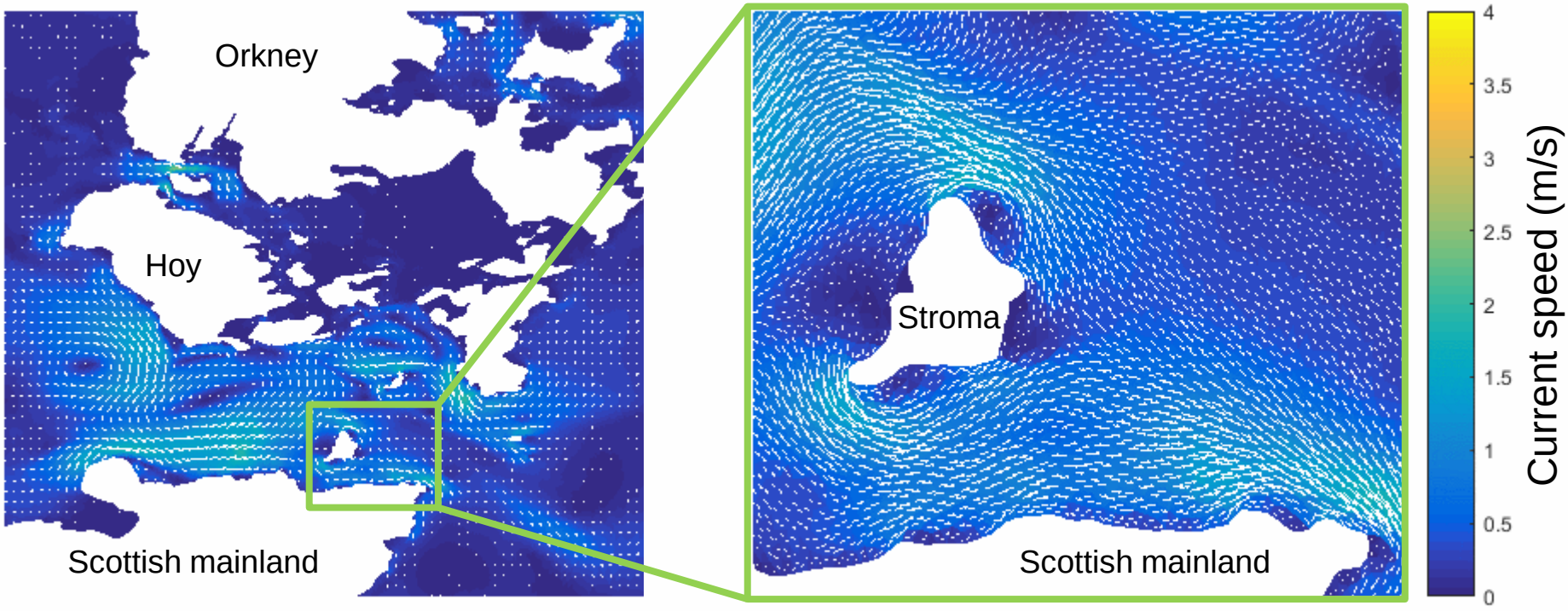
- FVCOM model
- Unstructured grid, 3D, 10 depth layers
- ~ 100 m node spacing in the Pentland Firth
- M_2 tidal (elevation) boundary conditions





Modelled tidal currents (baseline)

marinescotland science



Tidal Turbine Parameterisation

marinescotland science

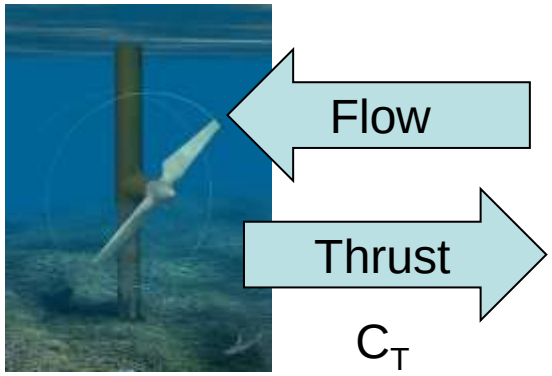
- Yang, Wang and Copping (2013) Renewable Energy

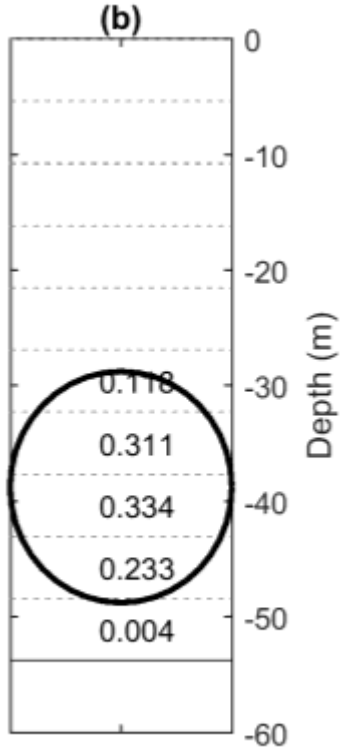
- Sub grid scale → Momentum Sink
- Additional body force terms in momentum equations:
- $\boldsymbol{F} = \frac{1}{2}\,\rho N C_T A_b |\boldsymbol{u}|\boldsymbol{u}$ assume turbines weathervane

- Retarding force equal and opposite to thrust
- C_T can be constant or speed dependent

- Fractional split between sigma layers

- For this work
- ***D* = 20 m**
- $C_T = 0.85$

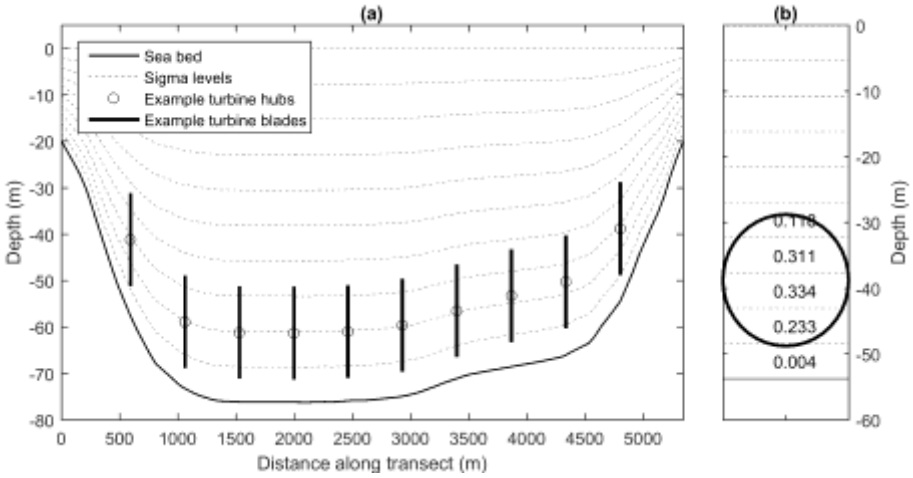


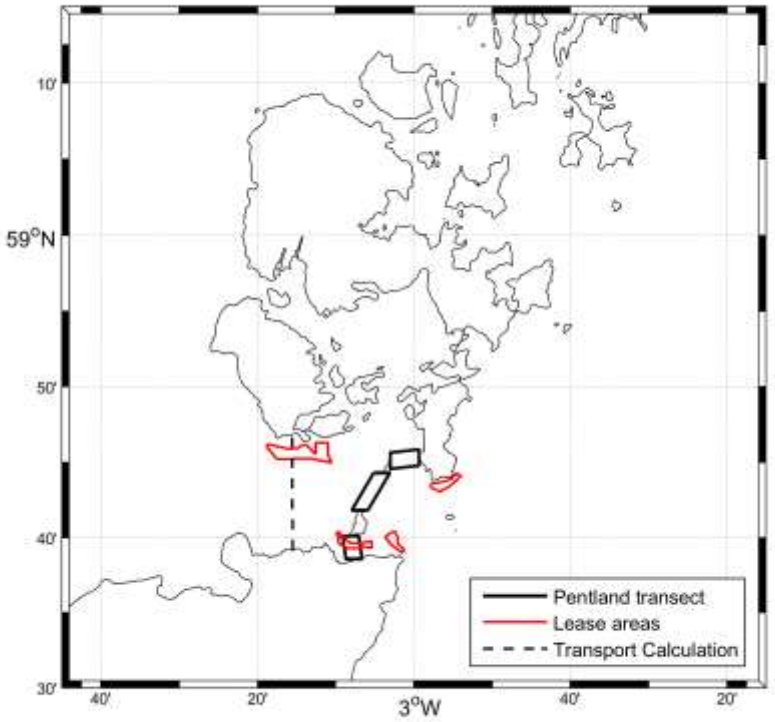


Tidal turbine array scenarios

1. **Pentland Firth transect**
   - 500 turbines
2. **Lease areas**
   - 800 turbines
   - 45 x 160 m spacing

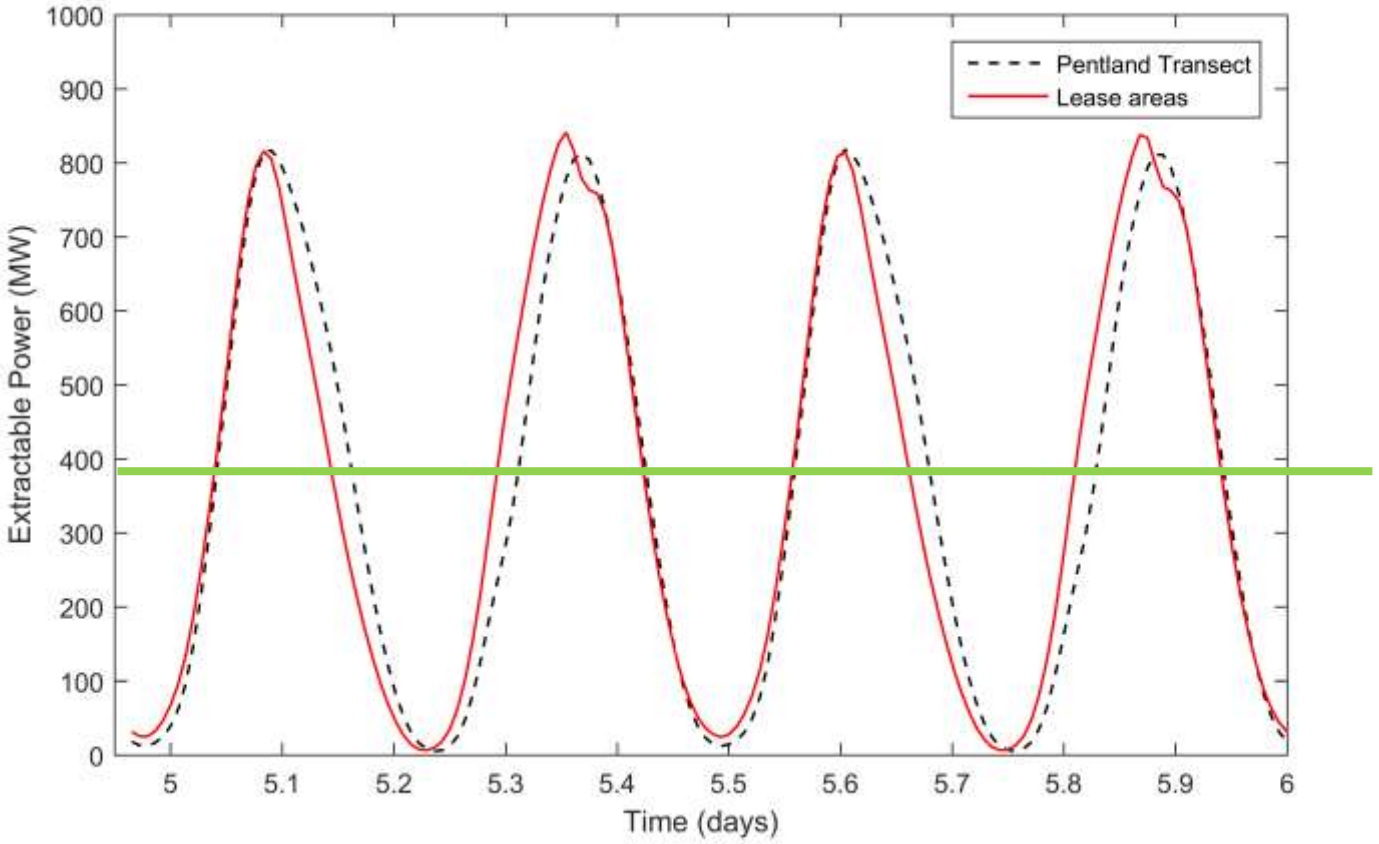
- **Turbines confined to near bed**





Extractable power time series

marinescotland science

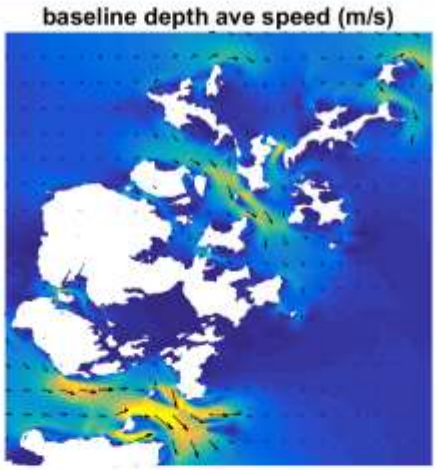


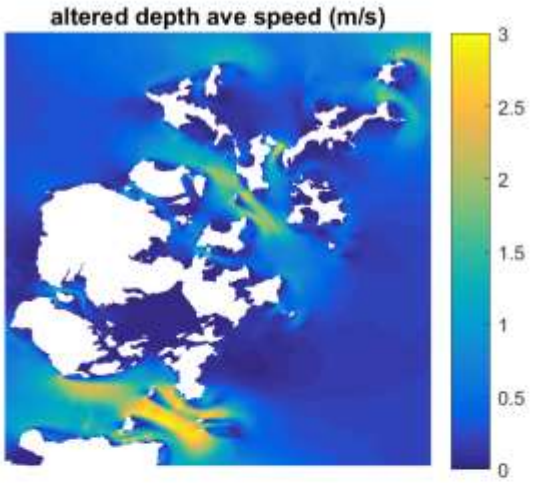
370 MW

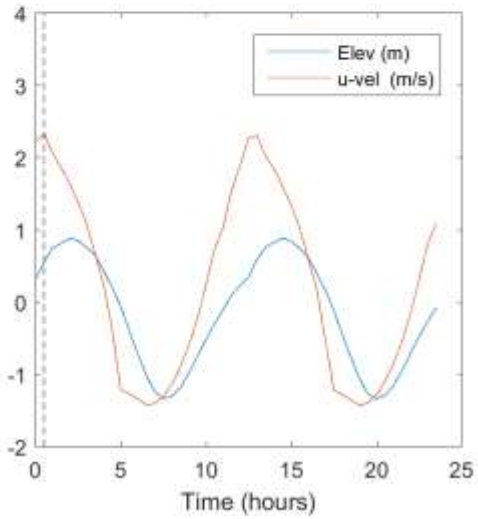
- Two scenarios producing similar levels of power on average
- 500 & 800 turbines

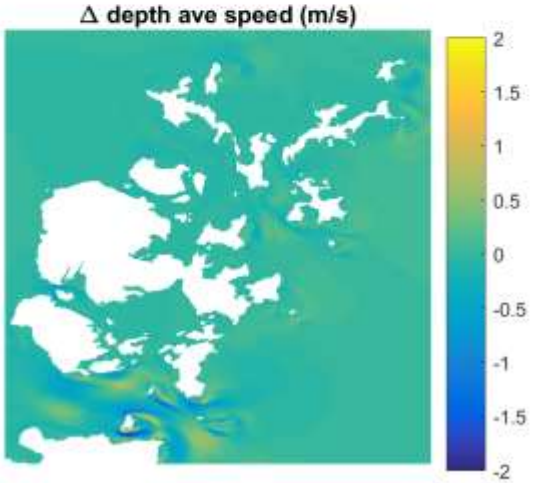
Instantaneous current speeds

marinescotland science



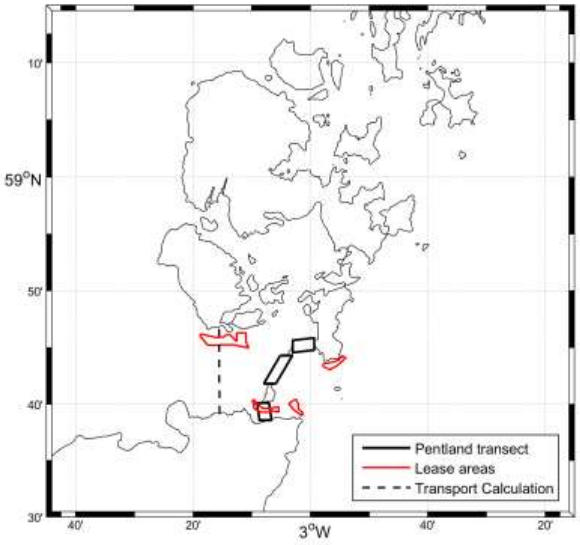


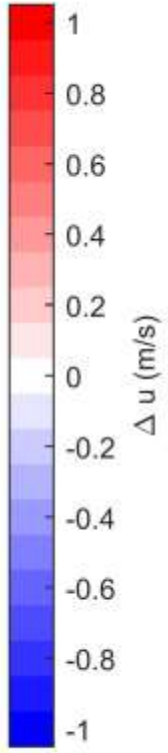




Changes to the M_2 tide – current speeds

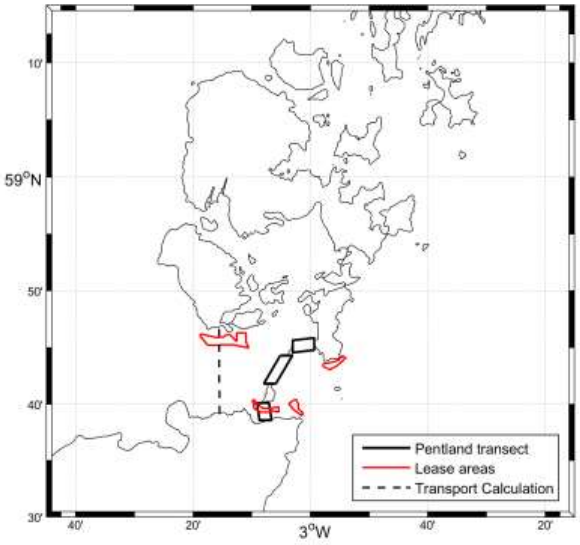
marinescotland science

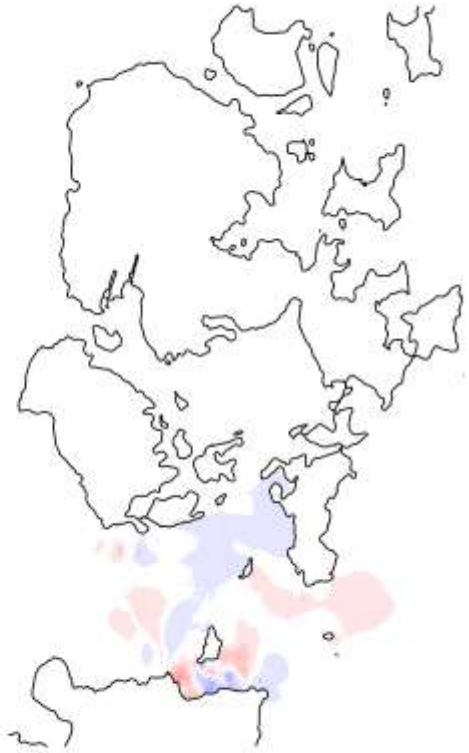


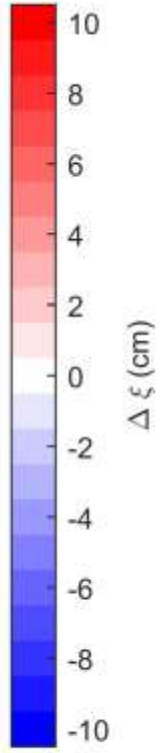


		Pentland Firth Transect	Lease Areas
Spatial area where	$\Delta u > 0.5$ m/s	0 km^2	6.1 km^2
	$\Delta u > 0.25$ m/s	0.1 km^2	16.3 km^2

Changes to the M_2 tide – water levels



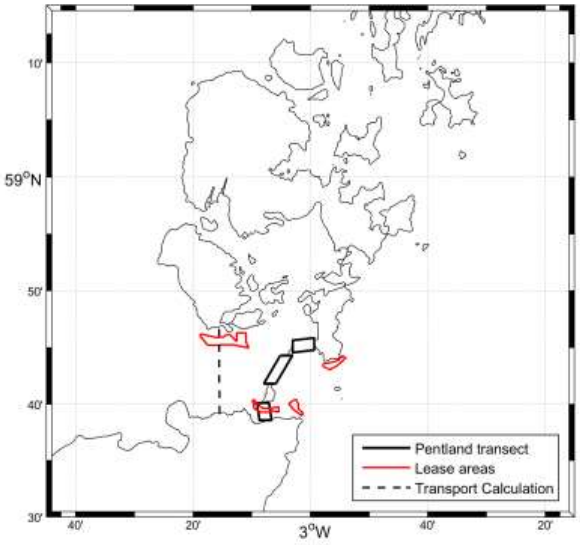


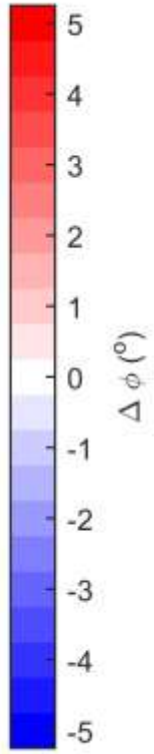


	Pentland Firth Transect	Lease Areas
Spatial area where $\Delta\xi > 2$ cm	0.2 km^2	7.2 km^2

Changes to the M_2 tide – tidal phase

marinescotland science

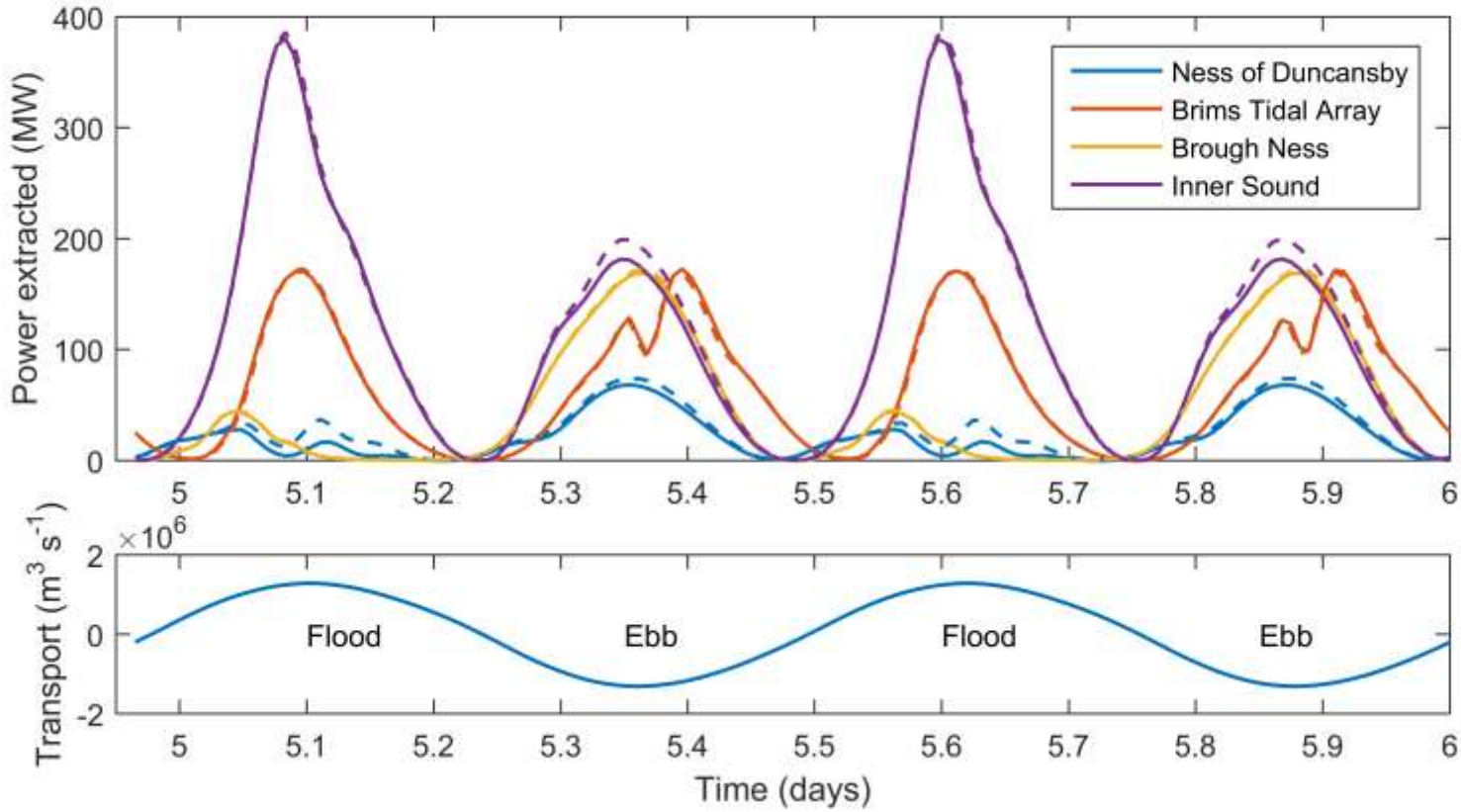




		Pentland Firth Transect	Lease Areas
Spatial area where	$\Delta ø > 5^{\circ}$	0 km^2	0.4 km^2
	$\Delta ø > 2.5^{\circ}$	0.3 km^2	0.4 km^2

How much power can be extracted from the lease areas?

marinescotland science



- Mean average combined power is 370 MW
- There are interactions between the arrays

Conclusions

- **Two scenarios explored**
  - 370 MW on average
  - One more efficient
  - One more realistic
- **Both scenarios change the tide to some extent**
- **Spatial planning important**
  - Maximise power
  - Minimise environmental impact
- **Lease areas may interact**