Potential effects of large-scale tidal energy extraction in the Pentland Firth on the biogeochemistry in the North Sea

Johan van der Molen

johan.vandermolen@cefas.co.uk
The Centre for Environment, Fisheries and Aquaculture Science (Cefas)
Pakefield Road, Lowestoft NR32 4HJ, UK

Large Scale Interactive Coupled Modelling of Environmental Impacts of Marine Renewable Energy Farms (LINC, EPSRC grant EP/J010065/1)

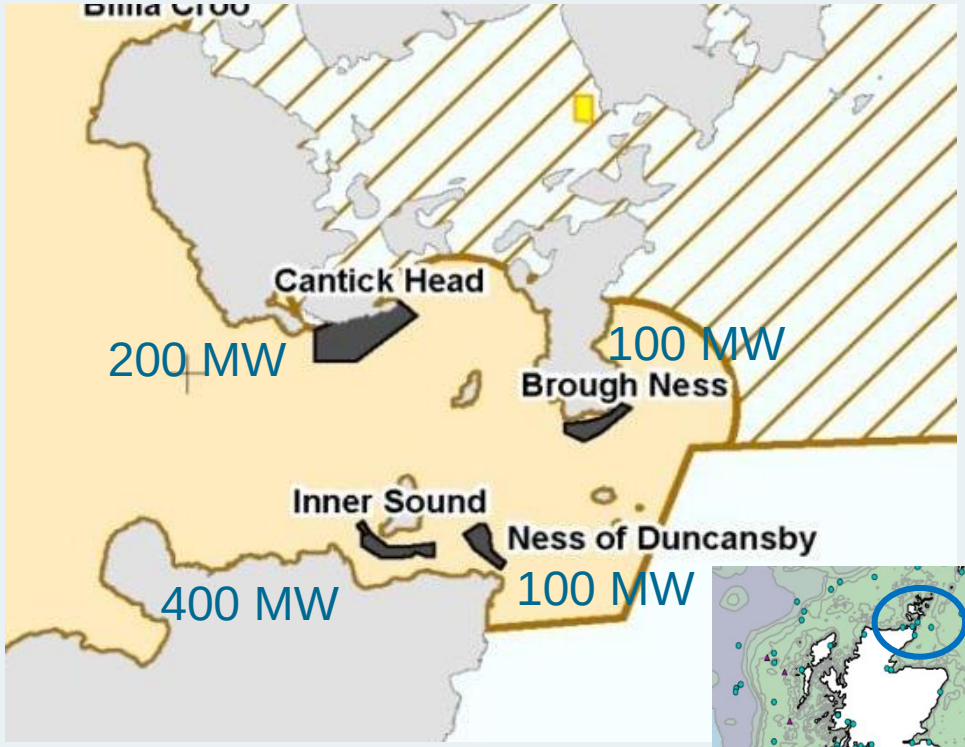
Van der Molen, J., Ruardij, P., Greenwood, N., 2016. Potential environmental impact of tidal energy extraction in the Pentland Firth at large spatial scales: results of a biogeochemical model. Biogeoscienses 13, 1-17, doi: 10.5194/bg-13-1-2016.

Centre for Environment Fisheries & Aquaculture Science

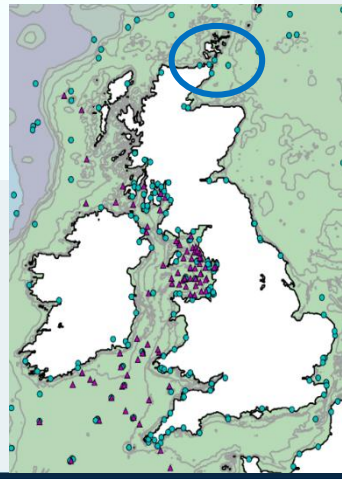
Cefas

Tidal turbines in the Pentland Firth

- Turbine farms licensed
- This study: investigate large-scale effects
- Tides
- Biogeochemistry, primary production and benthos
- Model: GETM-ERSEM-BFM[1,2]



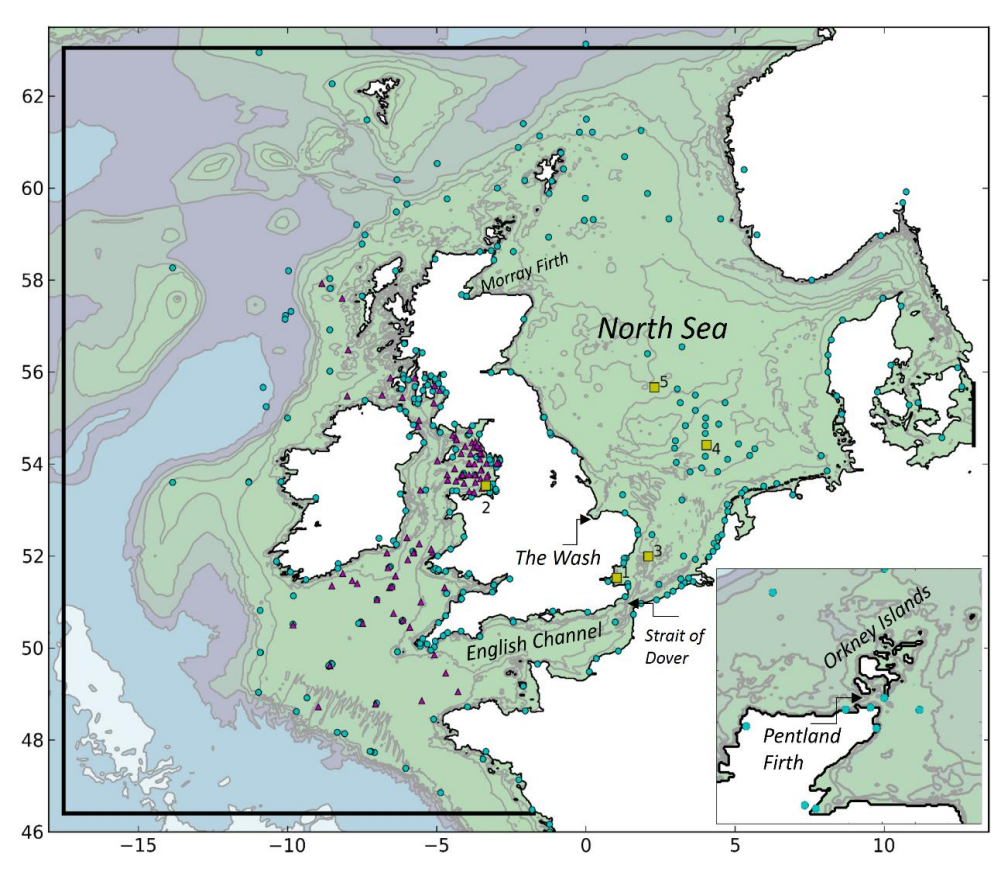
Licenced areas, The Crown Estate (2013)[3]



[1]www.getm.eu
[2]www.nioz.nl/ersem-getm
[3]The Crown Estate: Pentland Firth and Orkney Waters Strategic Area Review Project, 8pp., www.thecrownestate.co.uk/media/5446/pfow-strategic-area-review-project-2012.pdf, 2013.

GETM hydrodynamics: Northwest European Shelf

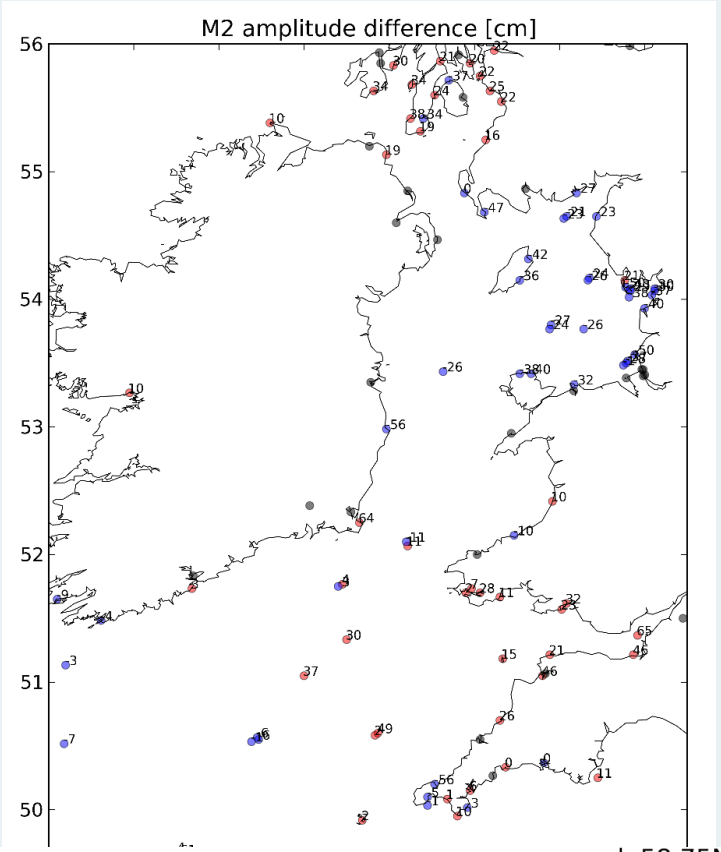
- 5 km horizontal resolution
- 25 layers in vertical
- Forcing:
  - Tides (Topex-Poseidon)[1]
  - Meteorology (ECMWF)[2]
  - Rivers (runoff, nutrients)[3]
  - Ocean boundary:
    - Temperature and salinity from ECMWF global model[4]
    - Nutrients from WOA (climatology)[5]

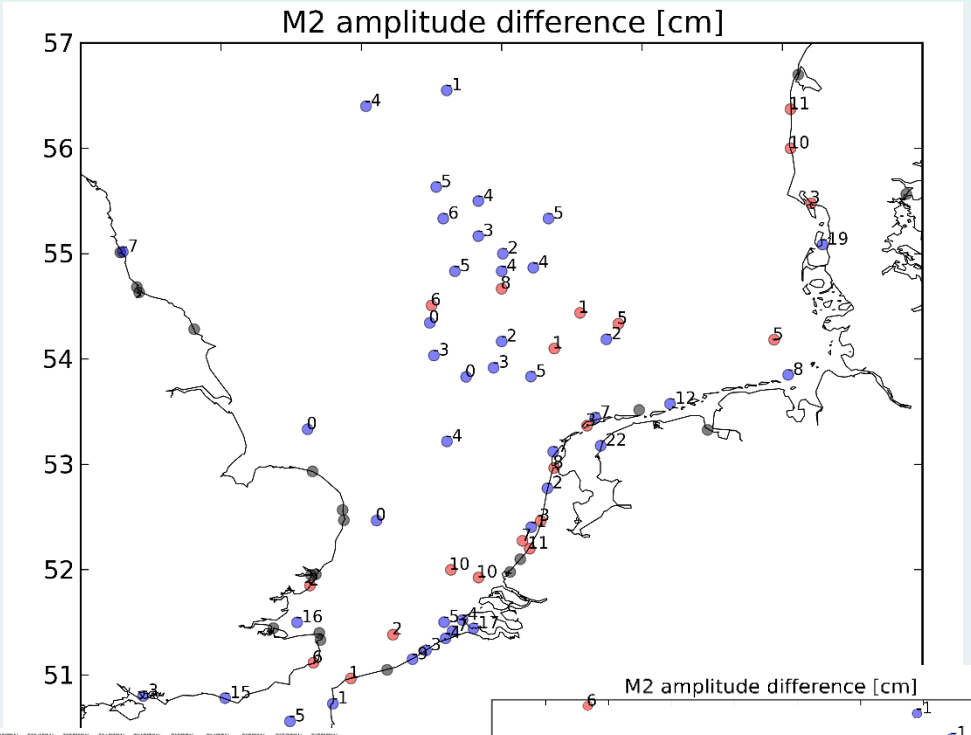


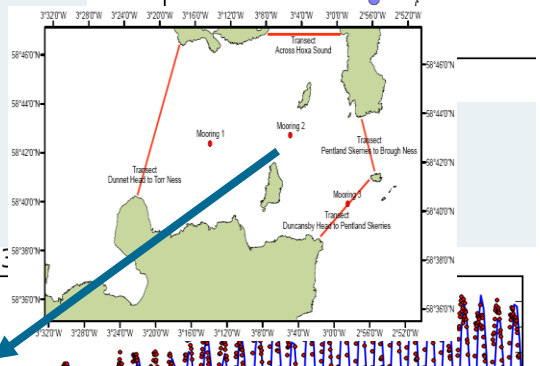
Model setup developed in collaboration with JRC, Ispra, Italy

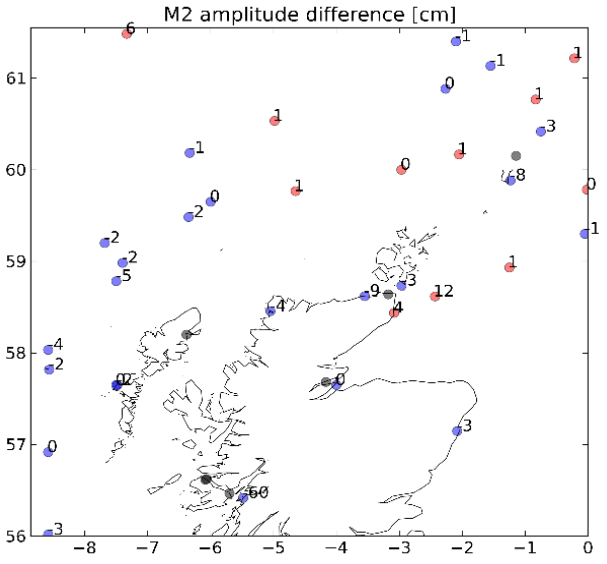
[1]Le Provost et al. 1998 JGR 103, C3, 5513-5519.
[2]ECMWF 2006 ERA-40, Operational Analysis, catalogue.ceda.ac.uk
[3]Combined observational data sets
[4]Balmaseda et al. 2013 QJR Met Soc 139, 1132-1161
[5]Garcia et al. 2010 World Ocean Atlas 2009 V4 Nutrients, NOAA

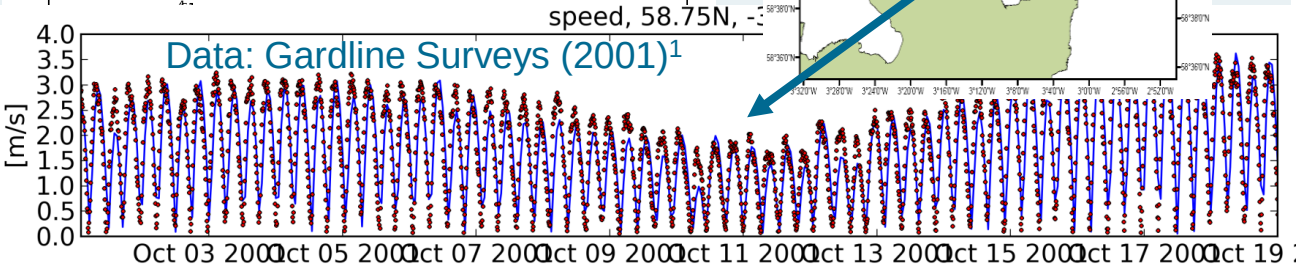
Tidal validation





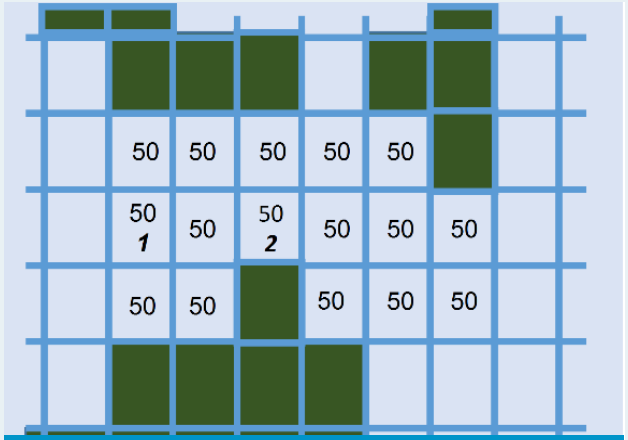






Tidal power extraction in GETM

- Generators:
  - Assumed main dimensions of Triton 3 Tidal Stream Generators:
    - 1 MW rotors
    - D_{rotor}=20 m
  - Assumed C_{thr}=0.6
- Power extraction scenario's:
  - 800 MW (licenced), evenly distributed
  - 8 GW (massive expansion), evenly distributed



1 MW rotors per model grid cell

Additional sink term momentum eqns:

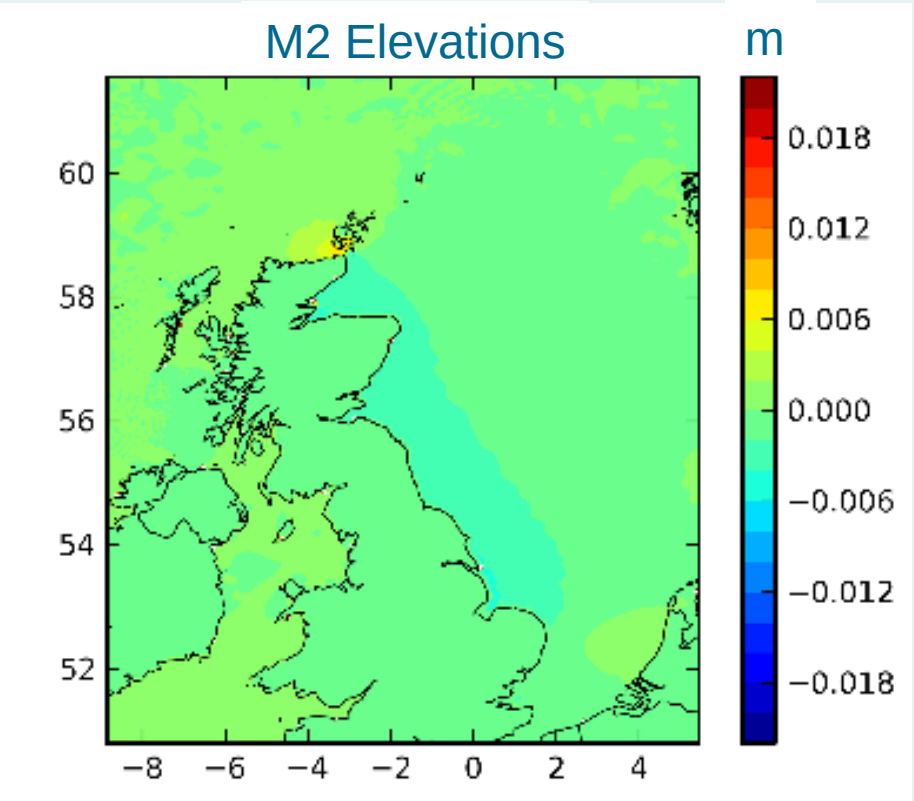
$$S_{f,u} = C_{d,t} u \sqrt{\left(u^2 + v^2\right)}$$

Friction coefficient per turbine (rotor):

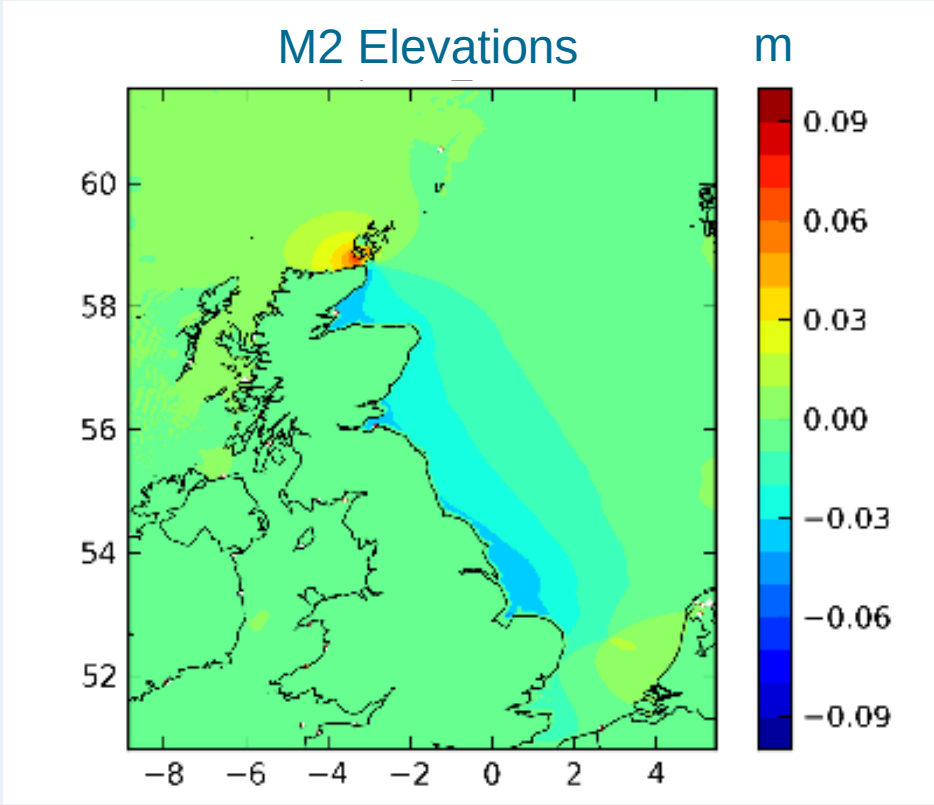
$$C_{d,t} = \frac{1}{2} N C_{thr} \frac{\frac{\pi}{4} D_{rotor}^2}{dxdyH}$$

Applied throughout the water column

Results: Differences tides



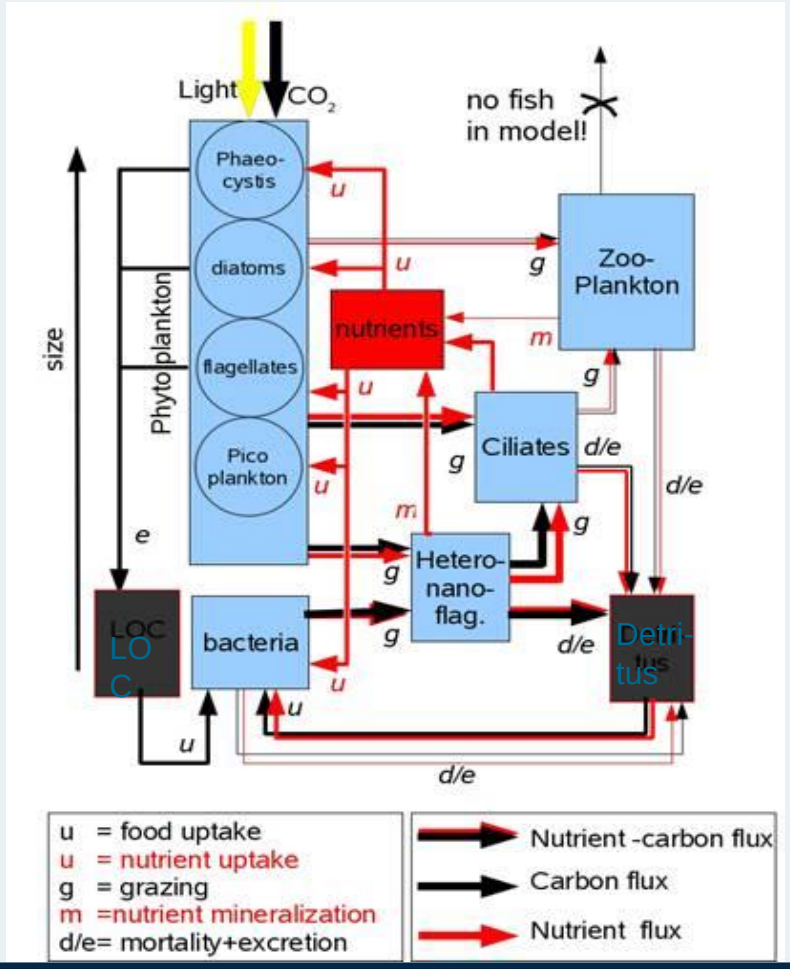
800 MW extraction



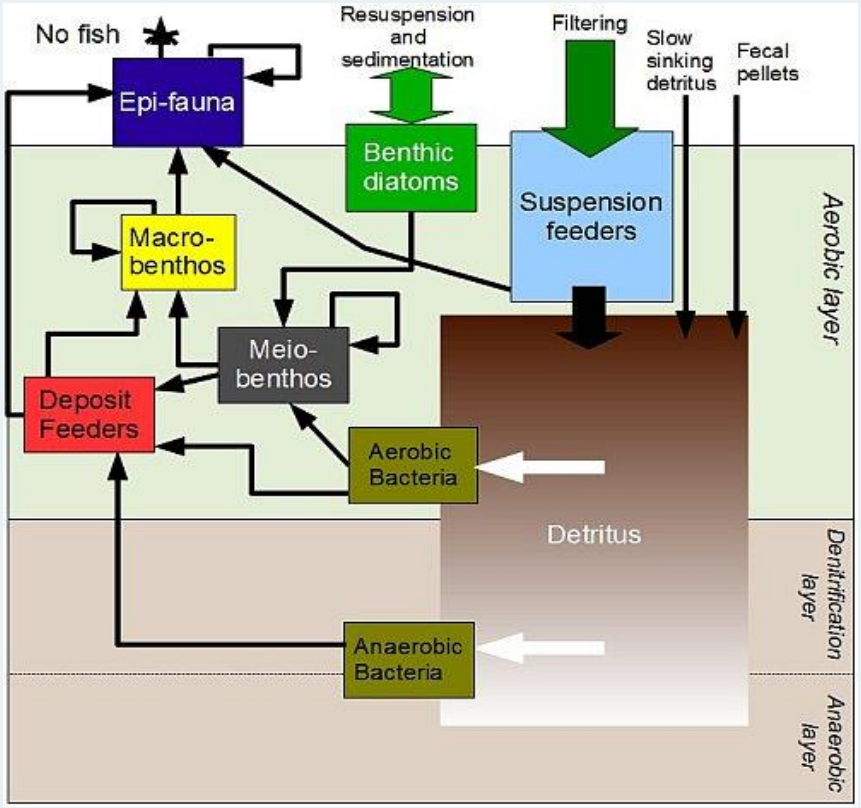
8 GW extraction

Difference = Scenario - Reference

European Regional Seas Ecosystem Model (ERSEM-BFM)[1]

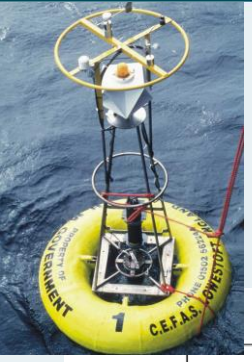


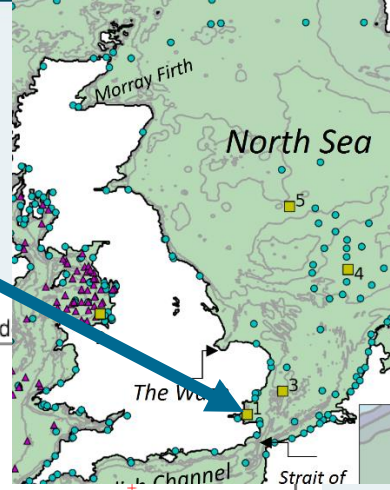
Pelagic

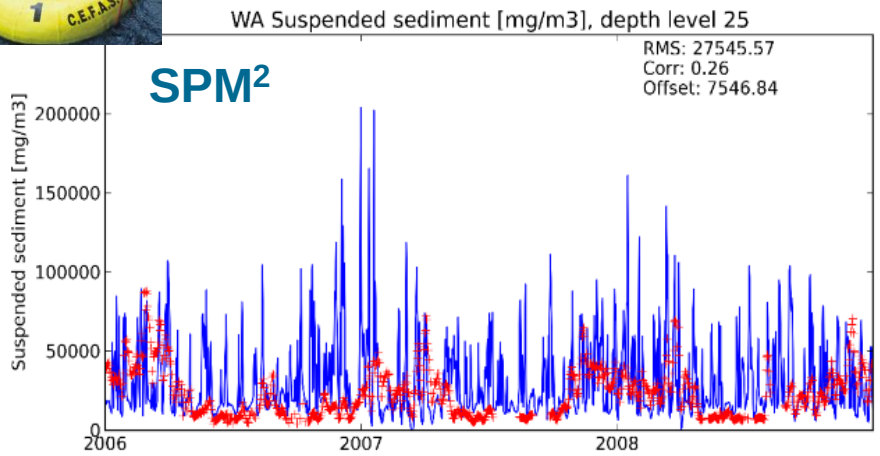


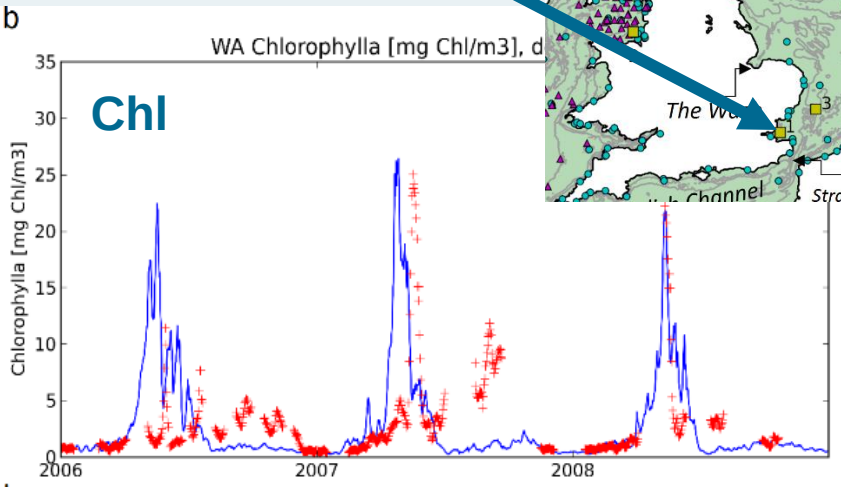
Benthic

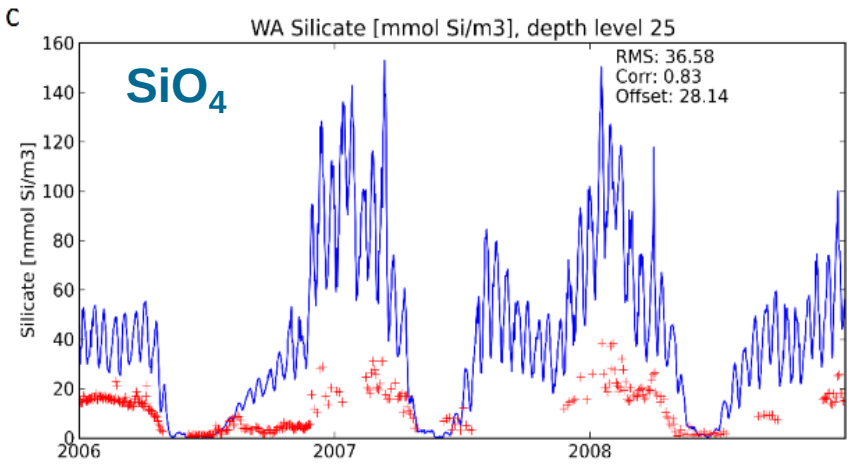
Validation: Warp Anchorage SmartBuoy[1]

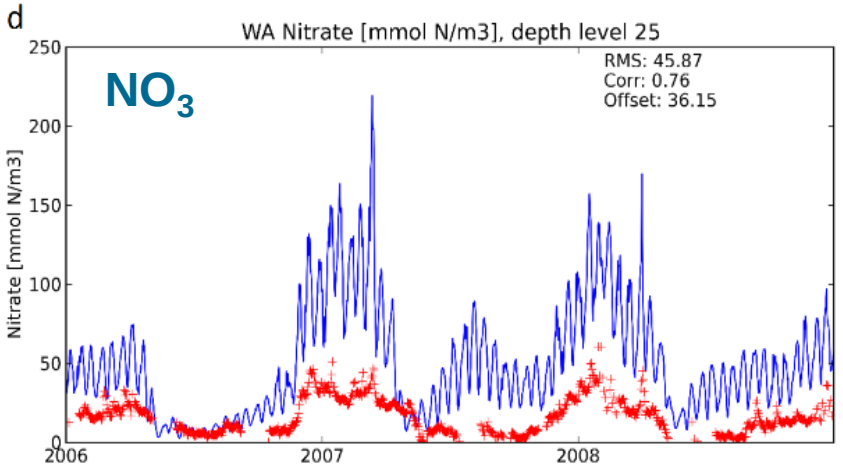










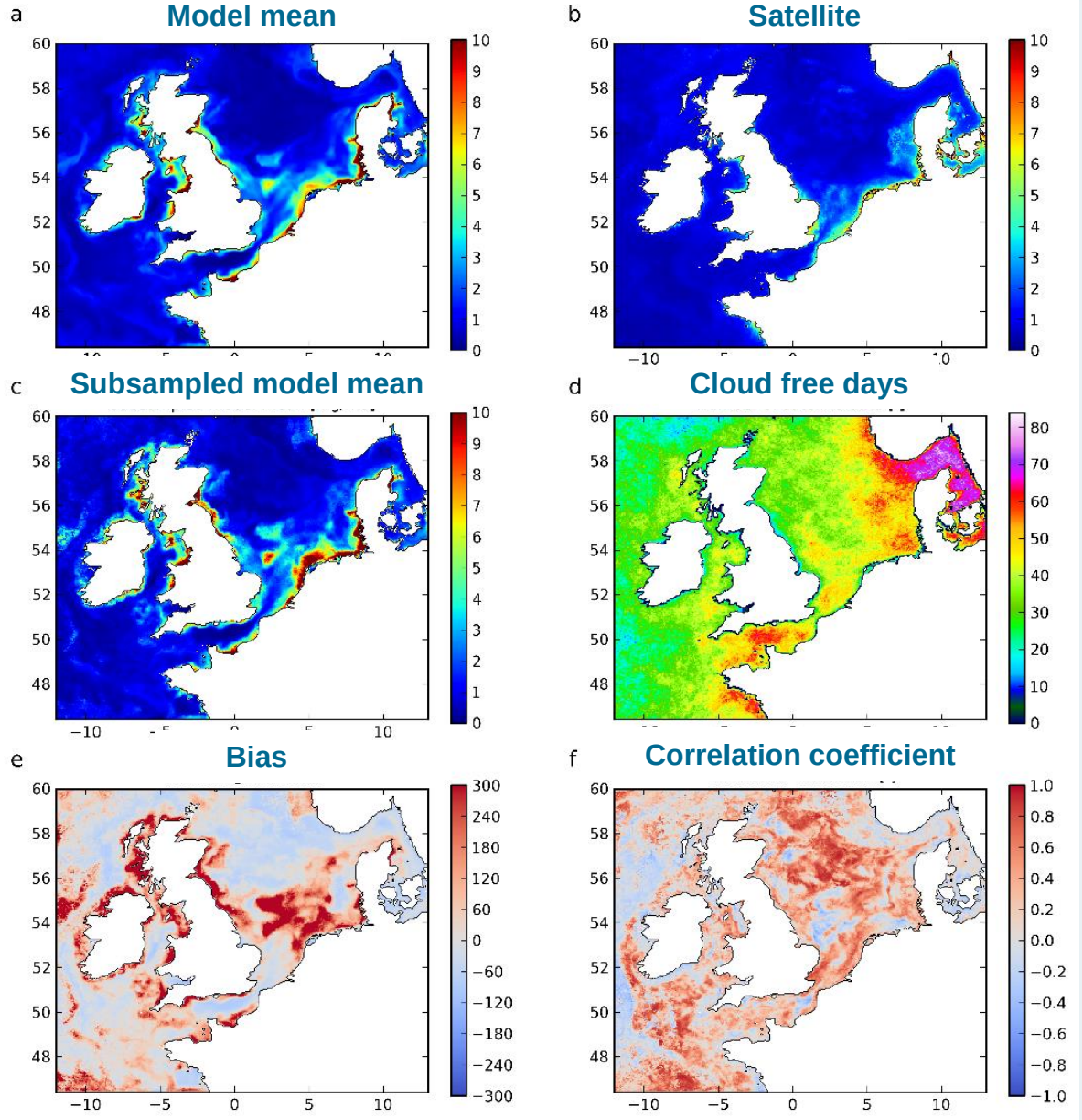


Centre for Environment Fisheries & Aquaculture Science

[1]www.cefas.co.uk/cefas-data-hub/smartbuoys
[2]SPM model: Van der Molen et al., 2016, J. Mar. Sci, under review

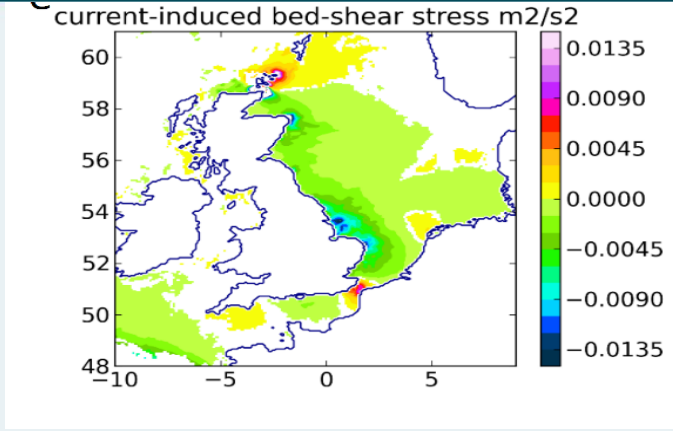
Cefas

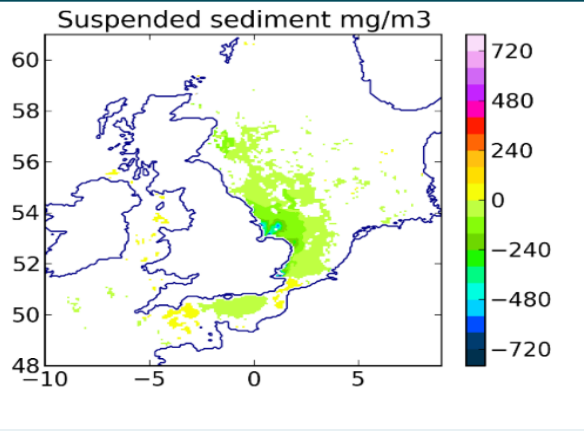
Summer chlorophyll: comparison with MODIS[1] satellite observations[2,3]

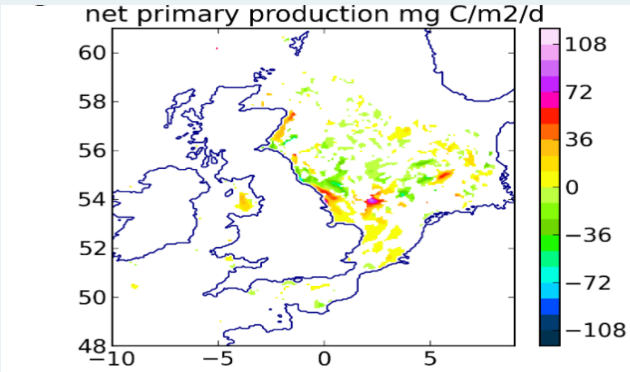


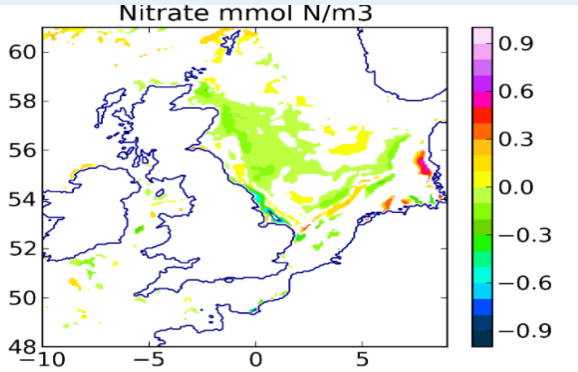
[1]modis.gsfc.nasa.gov
[2]Gohin et al 2005, RSE 95, 29-46
[3]Gohin 2011, Ocean Sci 7, 705-723

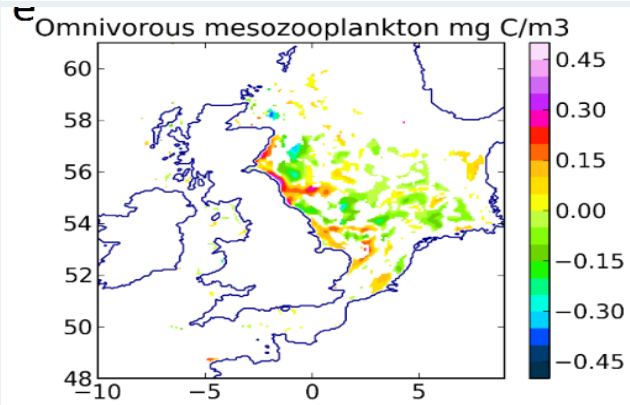
Results: 8 GW scenario

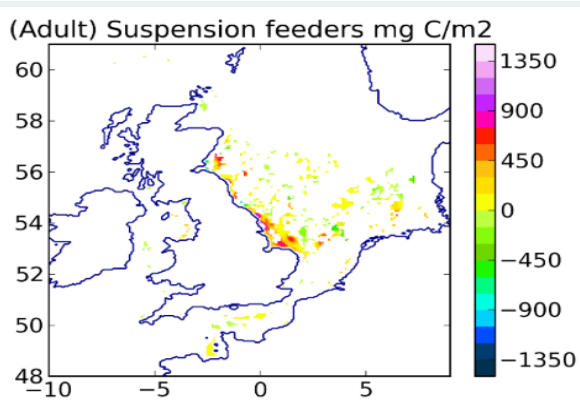












Conclusions

- Tides:
  - 800 MW: small effect (not measurable)
  - 8 GW: small effect up to southern Bight (measurable)
- Biogeochemistry:
  - 800 MW: no identifiable effect
  - 8 GW: small increase in production and biomass in large area around the Wash
- Process driven by reductions in bed-shear stress, SPM concentrations and light limitation