

Hydrodynamics in the Pentland Firth: Understanding the energy source

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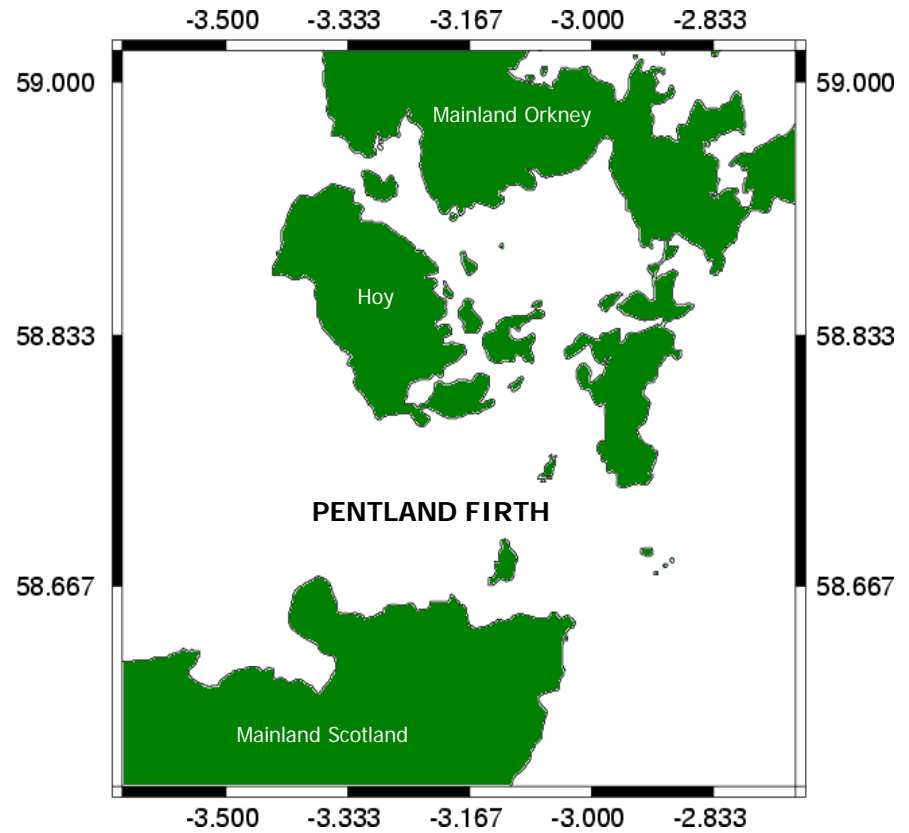
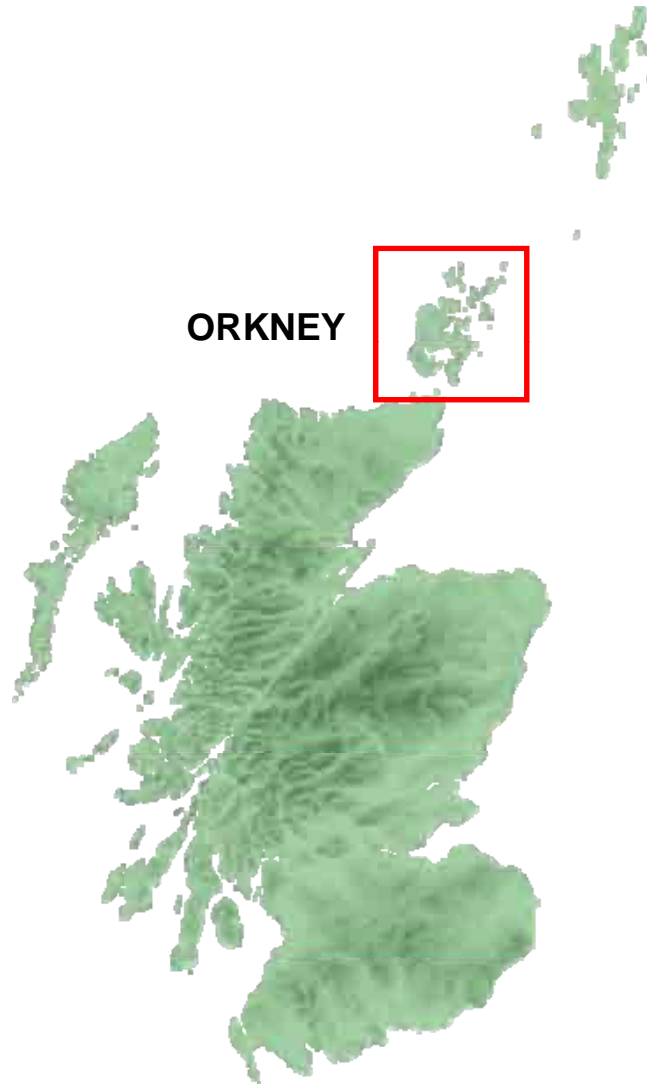
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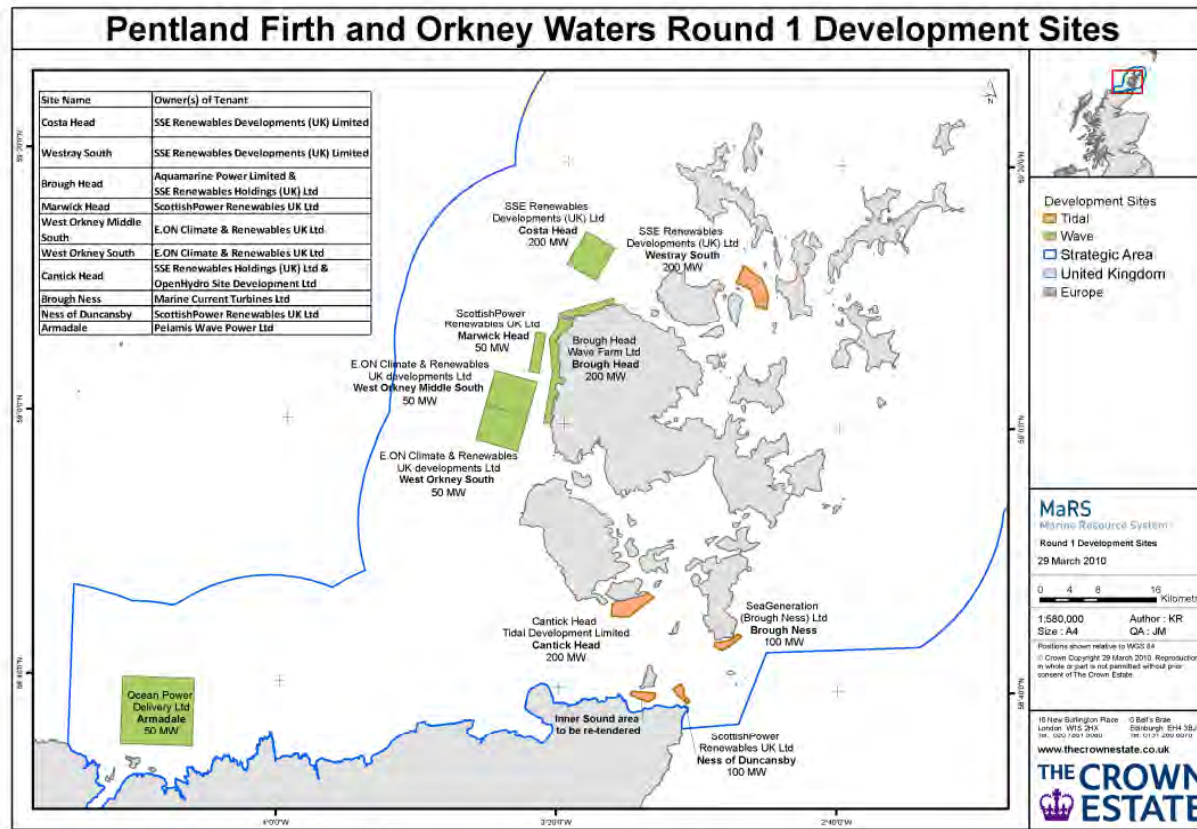


Motivation





Motivation



- The Physical environment and the ecology of the Pentland Firth are still not well understood
- Better picture of baseline environmental conditions must be done



Motivation

How good is the energy source?
How is the energy dissipated?
Long term and far-field effects

Uncertainty in Forcing

- ▶ Changes in Tidal forcing
- ▶ Hydrographic Changes

Uncertainty in Far-Field effects

- ▶ Shoreline changes
- ▶ Nutrients transport

Uncertainty in Underlying Processes

- ▶ Scales of resolution
- ▶ Water column structure
- ▶ Turbulence closure
- ▶ Sediment Transport





Motivation

- ❑ Initial site selection, mitigate impacts, maximise efficiency
- ❑ Predict effects of installation of MECs and harness energy from a flow field
- ❑ Monitoring tool both time and cost efficient
- ❑ Near and far field spatial information
- ❑ Long term temporal modelling
- ❑ Accurate predictions of nutrients and sediment transport in coastal waters





SUNTANS model



SUNTANS is a numerical model designed for the simulation of complex, non-hydrostatic coastal, river and estuarine flows with high resolution on unstructured grids using parallel computers.



SUNTANS model

Navier-Stokes simulator means that solve the Navier-Stokes equations:

$$\nabla \cdot \mathbf{u} = 0,$$

$$\frac{\partial u}{\partial t} + \nabla \cdot (\mathbf{u}u) - fv + bw = -\frac{1}{\rho} \frac{\partial q}{\partial x} - g \frac{\partial \eta}{\partial x} + \nabla_H \cdot (v_H \nabla_H u) + \frac{\partial}{\partial z} \left(v_V \frac{\partial u}{\partial z} \right),$$

$$\frac{\partial v}{\partial t} + \nabla \cdot (\mathbf{u}v) + fu = -\frac{1}{\rho} \frac{\partial q}{\partial y} - g \frac{\partial \eta}{\partial y} + \nabla_H \cdot (v_H \nabla_H v) + \frac{\partial}{\partial z} \left(v_V \frac{\partial v}{\partial z} \right), \text{ and}$$

$$\frac{\partial w}{\partial t} + \nabla \cdot (\mathbf{u}w) - bu = -\frac{1}{\rho} \frac{\partial q}{\partial z} + \nabla_H \cdot (v_H \nabla_H w) + \frac{\partial}{\partial z} \left(v_V \frac{\partial w}{\partial z} \right).$$

u, v, w are Cartesian components of velocity

\mathbf{u} is the vector form of velocity

q is the non-hydrostatic component of pressure

η is the free surface elevation

f and b are the Coriolis terms

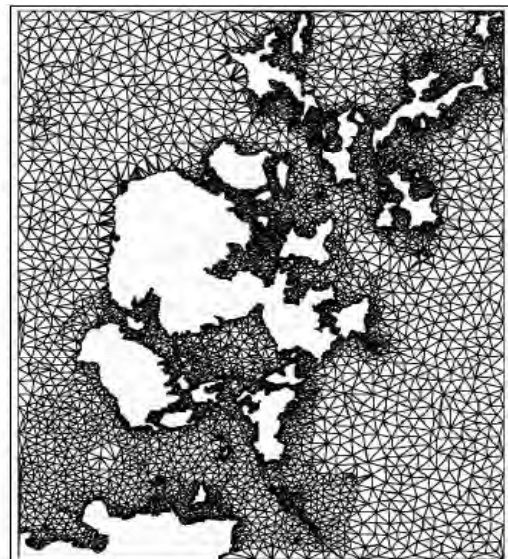
v_H and v_V are the horizontal and vertical turbulent eddy viscosities

∇_H the horizontal gradient operator: $\nabla_H = \frac{\partial}{\partial x} \hat{i} + \frac{\partial}{\partial y} \hat{j}$

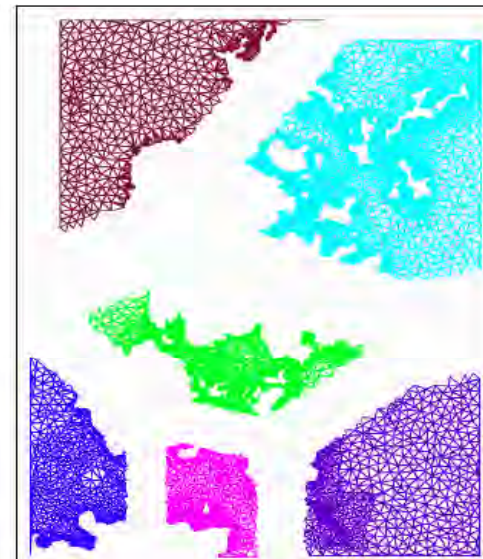


SUNTANS model

- ⇒ Open source: Accessible to research
- ⇒ Three-dimensional approach to resolve vertical
- ⇒ Unstructured grid: Provides exceptional resolution around fine-scale features
- ⇒ Parallel Implementation facilitates high resolution



Example unstructured grid of the sea around Orkney. The white areas indicate the islands and the Scottish mainland.



Grid partitions allowing loads to be split between each of six processors

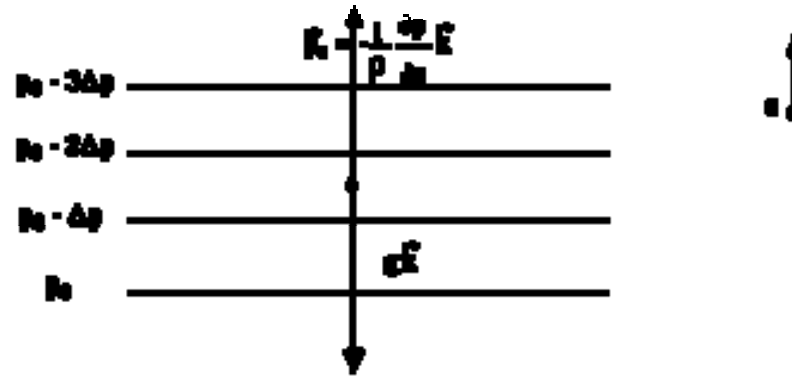
Resource: Dr Rob Harris¹, Dr Karl Stephen², Prof Margot Gerritsen³
1.- ICIT/HWU, 2.- IPE/HWU, 3.- Stanford University



SUNTANS model

Hydrostatic approximation: Equilibrium between pressure gradient and gravitational force

$$\frac{\partial p}{\partial z} = -\rho g$$



SUNTANS is **Non-hydrostatic**:

When a fluid is in motion, the vertical pressure gradient is also influenced by the vertical acceleration and friction → non-hydrostatic pressure effects

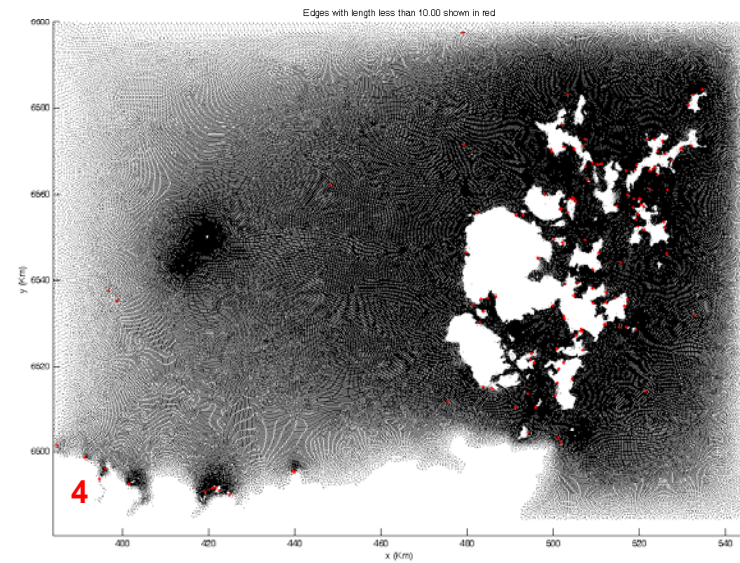
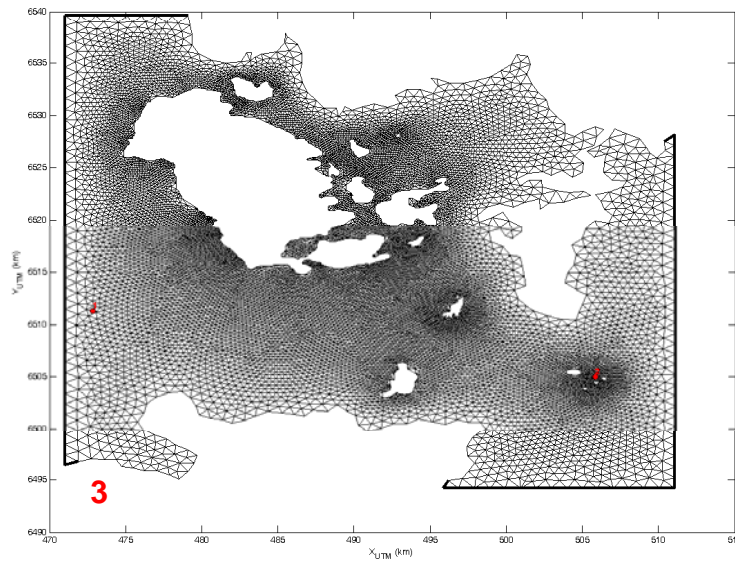
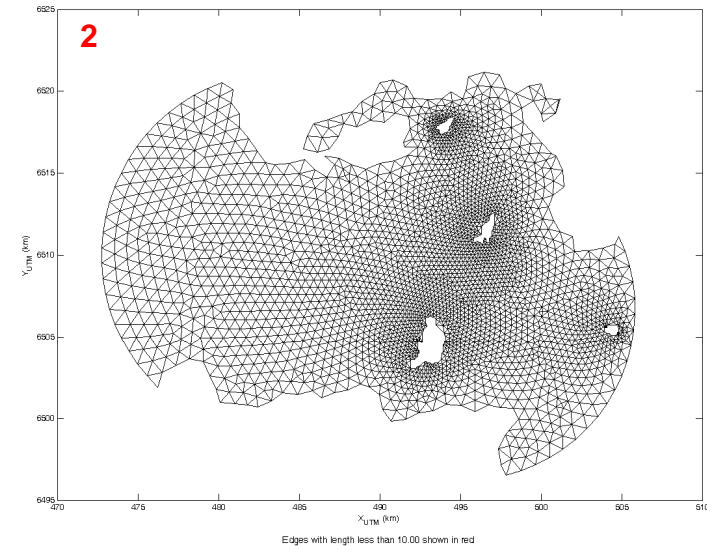
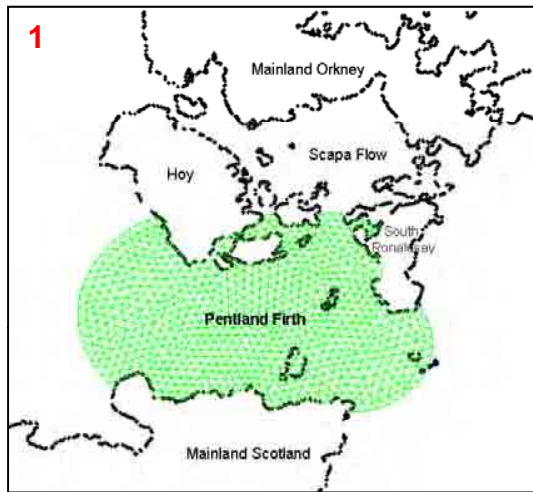
$$P = p + q$$

Static pressure + Dynamic pressure

- Bottom density currents at high latitudes
- Super critical flows related to topography in fjords and inlets



Implementation to the Pentland Firth

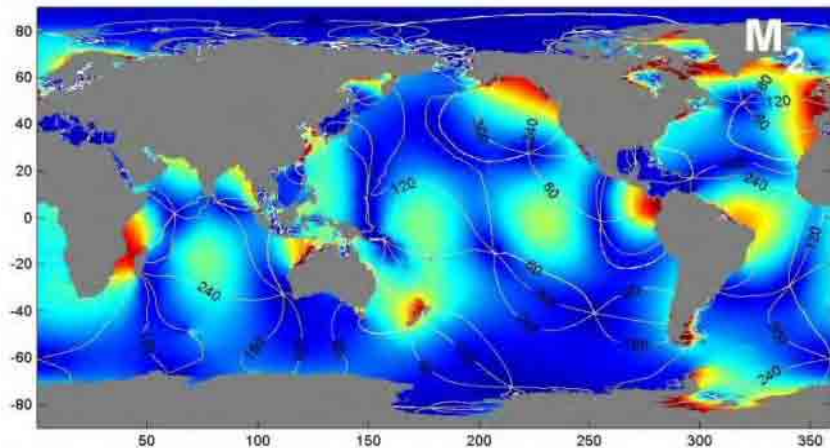




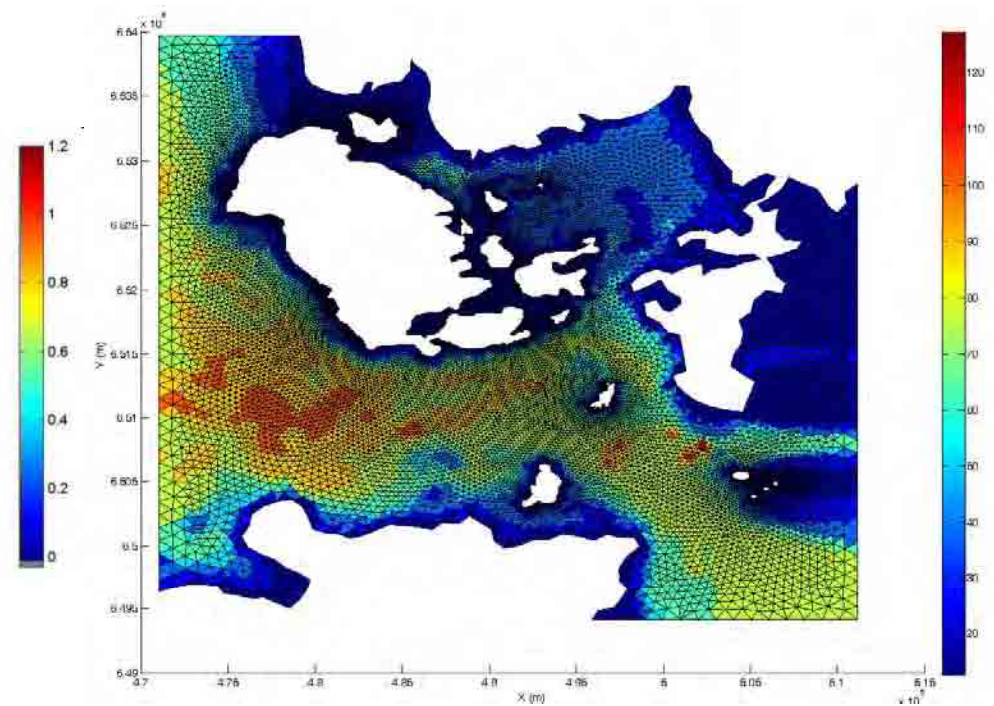
Implementation to the Pentland Firth

Boundary conditions

OSU TOPEX/POSEIDON Global inverse solution



Bathymetry interpolated onto the grid





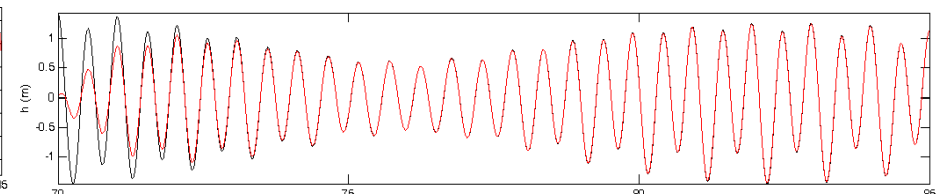
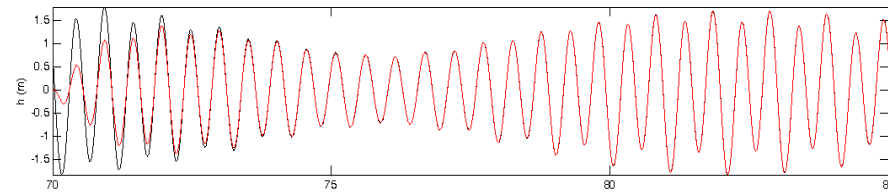
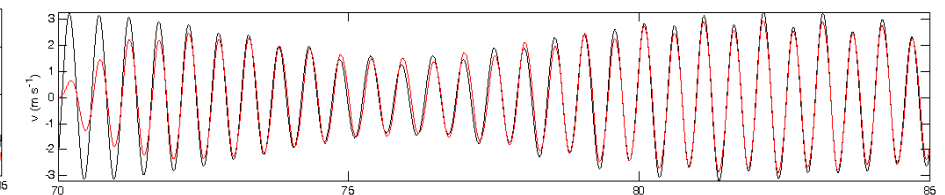
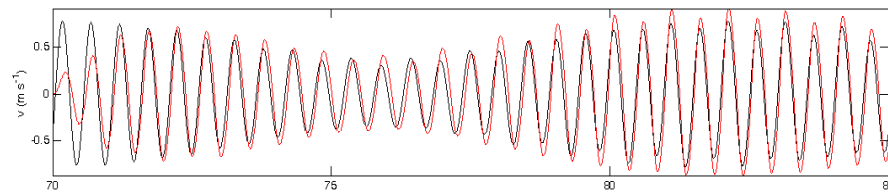
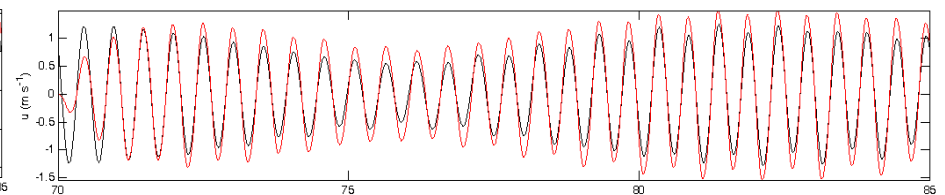
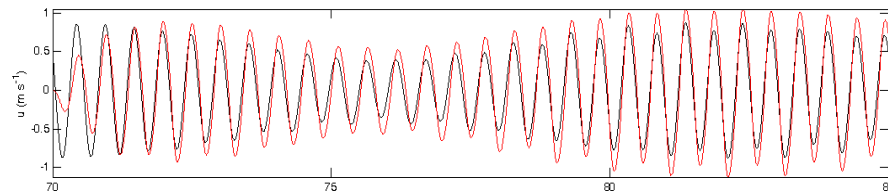
Implementation to the Pentland Firth

West Side

Coordinates: 476925, 3871, 6517493

East Side

Coordinates: 501079, 3, 6500478



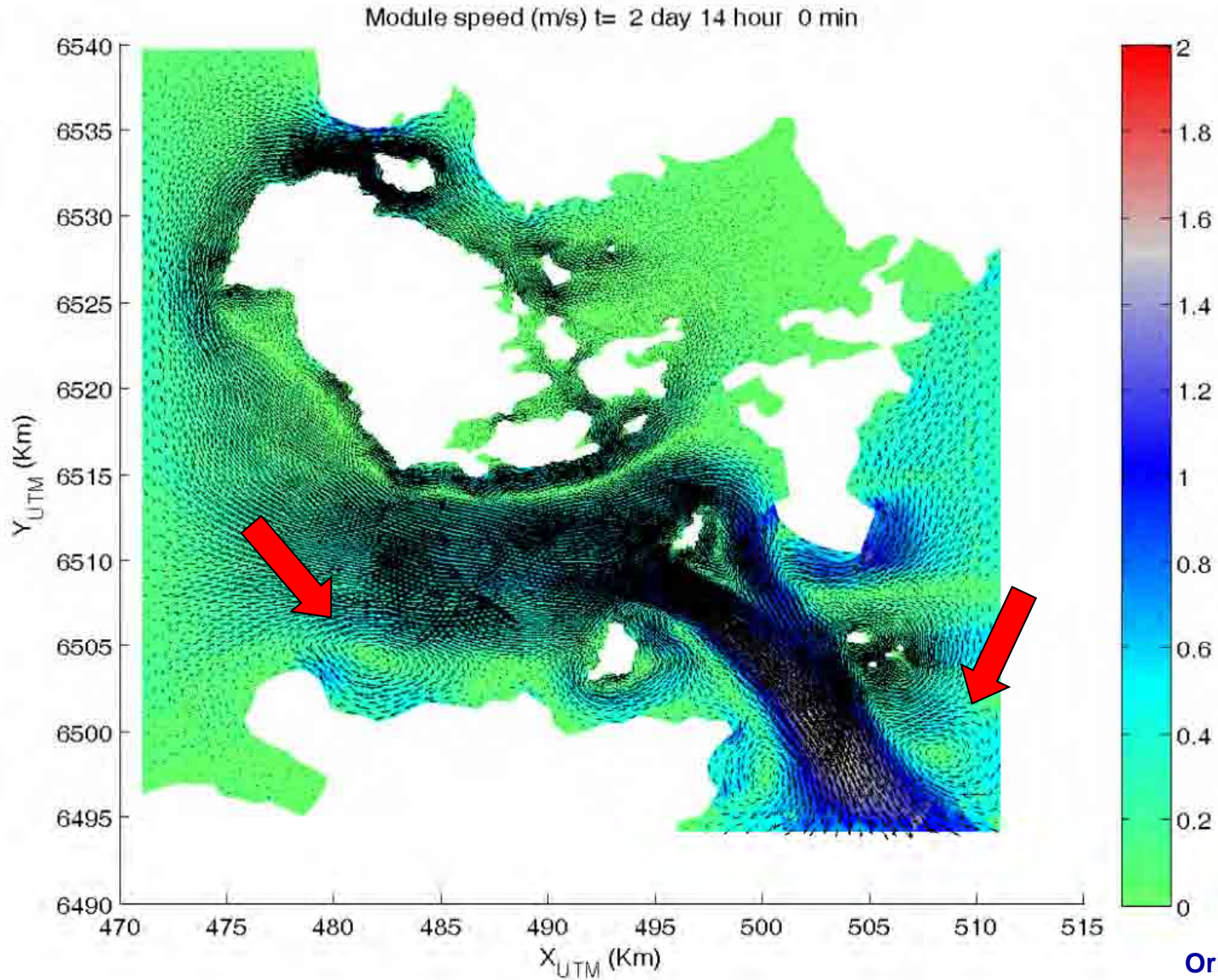
Days in 2008 (SUNTANS: red, OTIS: black)

Days in 2008 (SUNTANS: red, OTIS: black)



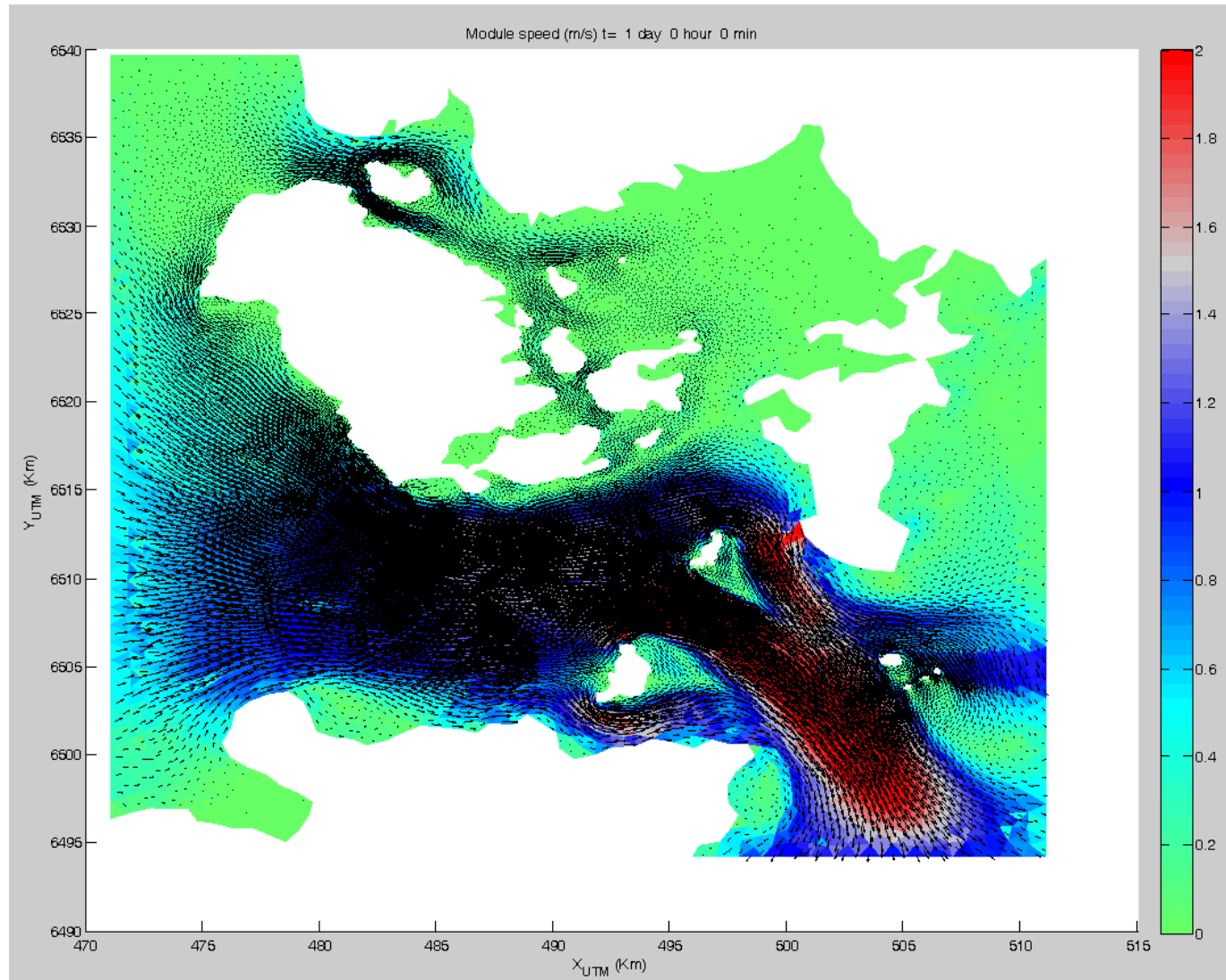


Implementation to the Pentland Firth





Implementation to the Pentland Firth



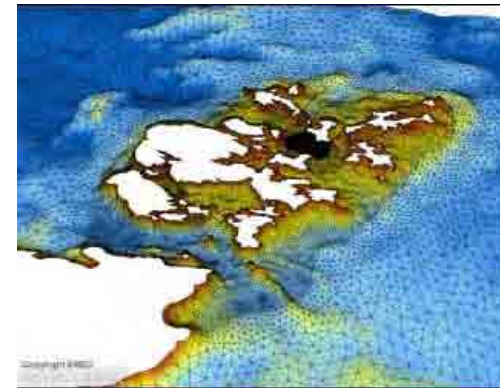


Future Work

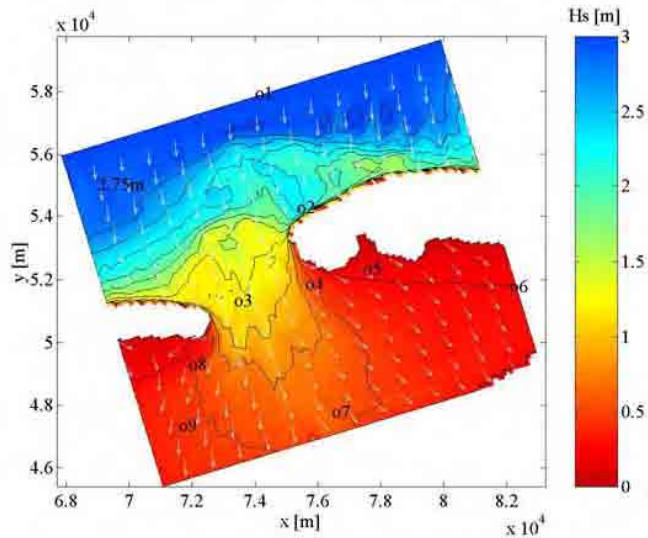
Calibration using ADCP data



Comparison with other numerical models



Coupling SUNTANS with wave models



Coupling with ecological models





Conclusions

- ⇒ There is a requirement for cost effective accurate long term spatial modelling of the environment and a clearer understanding of physical conditions
- ⇒ SUNTANS model is a valuable tool, capable of providing information leading to a better understanding of the source and intervention effects at MEC sites.
- ⇒ Once we have the model validated we can implement it to another areas of interest in Orkney
- ⇒ SUNTANS is a powerful research instrument



Thanks for your attention!

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<http://www.icit.org.uk/>