Technical Meeting – 3 June 2020

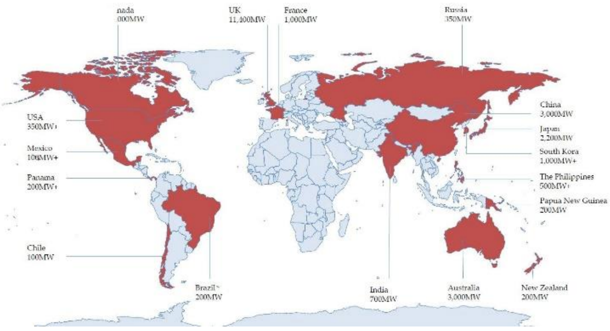
Christelle Auguste, PhD Candidate at the Australian Maritime College, University of Tasmania, and current holder of the Laurie Prandolini Award from the IMarEST, gave a presentation on *Investigation of Sediment Transport Processes near Tidal Energy Devices in Tasmania* as a webinar hosted by Engineers Australia with Phil Helmore as MC on 3 June. This was our second webinar presentation, and attracted 200+ registrations, with 150+ actually participating on the evening.

Introduction

Christelle began her presentation by asking the participants to imagine life without an energy supply! We need energy, and we must move towards renewable sources. The tide is renewable and relentless. Where the sun can energise photovoltaic panels for a variable handful of hours a day and the wind can blow turbines for days on end but, equally, disappear for extended periods without warning, the tide is near constant and entirely predictable.

The world's oceans cover about 71% of the planet, and there are many locations where tides ebb and flow with sufficient speed to generate energy. The estimates of the global potential of tidal energy generation vary, but it is widely agreed that tidal-stream energy capacity could exceed 120 GW.

The Pentland Firth in Scotland is widely considered to be one of the world's best sites for tidal power. The Bay of Fundy in Canada is also a promising location for tidal energy. China has abundant resources for tidal power, and other countries with significant tidal power potential include the USA, Argentina, Russia, France, India and South Korea. Australia and New Zealand have large ocean energy resources but do not yet generate any power from them.

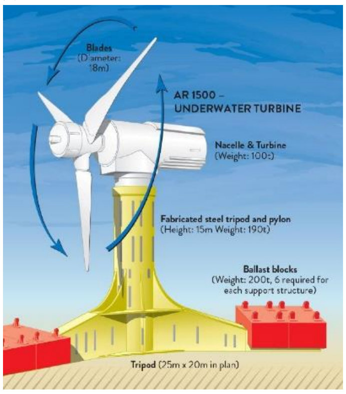


Areas of the world with estimation of potential tidal energy generation
(Chart from Offshore-Energy.biz website)

Tidal-current Energy Technologies

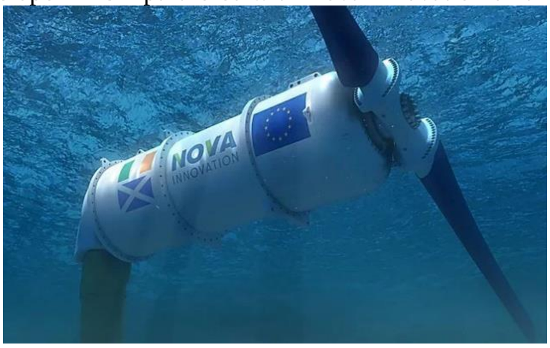
A number of companies already manufacture underwater turbines to harness the energy provided by tidal streams, including Naval Energies, Sabella and Blue Shark Power, all in France; Simec Atlantis Energy, Nova Innovation and Orbital Marine Power, all in Scotland; Hangzhou Lin Dong Ocean Energy Technology in China; and Mako Energy in Australia!

The Meygen tidal energy project is being developed by Simec Atlantis Energy (formerly Atlantis Energy) on a 3.5 km stretch in the Pentland Firth between the island of Stroma and mainland Scotland. Situated 2 km away from Scotland's north-east tip on a natural channel through which water flows between the North Sea and the Atlantic Ocean, the site boasts an average tidal current of 4.4 m/s, some of the fastest-flowing waters in the UK. The massive project is being developed in three phases, and reached 6 MW in 2018, with 28 MW in 2020 and an eventual planned capacity of 398 MW.



Turbine for the Meygen project
(Image courtesy Simec Atlantis Energy)

Also in Scotland, Nova Innovation deployed the world’s first fully-operational grid-connected offshore tidal energy array, at Bluemull Sound in the Shetland Islands. The first two Nova M100 turbines producing 100 kW at 2 m/s tidal speed were deployed at the site in 2016, and a third turbine was added to the array in early 2017. Belgian renewable energy developer ELSA partnered with Nova Innovation on the Shetland tidal array.



Turbine for the Shetland tidal array
(Photo courtesy Nova Innovation)

China’s first tidal power station of 3.4 MW capacity on Xiushan Island in China’s Zhejiang Province was connected to the grid on 25 May 2017. Also in 2017, the Chinese State Oceanic Administration released the *13th Five-year Plan for Marine Renewable Energy (2016-2020)*, which set out the key principles and specific actions for delivering the country’s potential in marine renewable energy. By 2020, China planned to build four marine renewable-energy demonstration districts, increasing the total installed capacity of marine renewable energy to over 50 MW in the following two years.

In France, the Ushant Island tidal project saw Sabella set up a tidal-stream generator in the Fromveur Passage between Ushant and the coast of Brittany. In June 2015, a Sabella D10 turbine was lowered into the Fromveur Passage in a water depth of 55 m and was then connected to the island network for testing and, subsequently, to the French grid. The generator is 17 m high and has a footprint of 20×20 m on the seabed; its 10 m diameter rotor can generate 1 MW from the 4 m/s currents in the Fromveur Passage.

Deployment of the turbine for the Ushant Island tidal project
(Photo courtesy Sabella)

Tidal Energy is Coming to Australia

Promising sites for tidal energy harvesting in Australia include the Banks Strait between Clarke Island in the Furneaux Group and Cape Portland on the north-east tip of Tasmania, and the Clarence Strait, between Melville Island and North West Vernon Island, north of Darwin in the Northern Territory.

Banks Strait
(Image courtesy AUSTEn)

AUSTEn is a $5.85 million three-year project to map Australia's tidal energy resources in detail, and assess their economic feasibility and ability to contribute to the country's energy needs. AUSTEn comprises:

- Project Lead — Australian Maritime College, University of Tasmania
- Research Partners — University of Queensland
  CSIRO
- Industry Partners — Mako Tidal Turbines
  OpenHydro (Naval Energies)
  Spiral Energy
  Simec Atlantis Energy
- Funding Agency — Australian Renewable Energy Agency (ARENA)
  Advancing Renewables Program

The project consists of three interlinked components to support the emerging tidal-energy sector. Component 1 will deliver a national Australian high-resolution tidal-resource assessment; Component 2 will conduct case studies at two promising locations for energy extraction; Component 3 will deliver technological and economic feasibility assessment for tidal energy integration to Australia's electricity infrastructure. The outcomes of this project will provide considerable benefit to the emerging tidal-energy industry, the strategic-level decision makers of the Australian energy sector, and the management of Australian marine resources by helping them to understand the resource, risks and opportunities available.

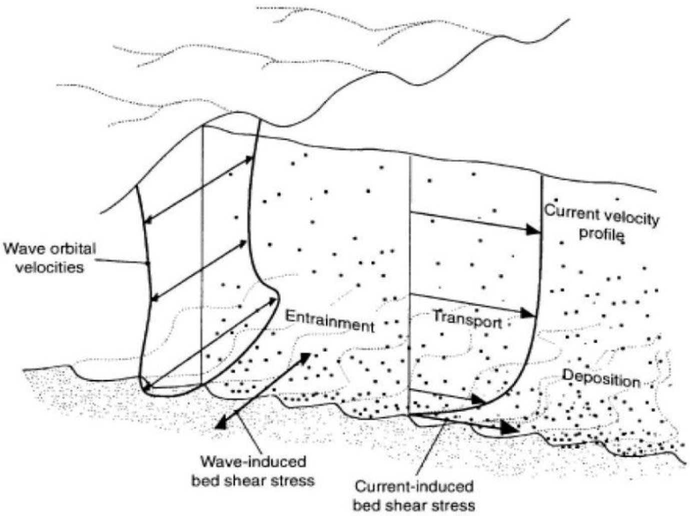
Why is Sediment Transport Important?

Tidal streams and wave action both have the ability to transport sediment on the sea bed. The wave orbital velocities generally move sediment back-and-forth parallel to the direction of wave travel. Tidal streams move sediment parallel to the direction of the stream, generally back-and-forth with the ebb and flow of the tide. The project is interested in the interaction of the turbines with the combined action of the waves and tidal streams.

Bed shear stress is the principal parameter acting on sediment dynamics. Most models defined the bed shear stress with the quadratic friction law

$$\tau_0 = \rho C_D \overline{U}^2$$

where ρ is the density of water, C_D the bottom drag coefficient and $\overline{U}$ the depth-averaged current speed.



Marine sediment transport processes
(Drawing from Soulsby, *Dynamics of Marine Sands*, 1997)

Sediment transport is responsible for the dynamics of sandbanks, influences morphodynamics (coastal erosion and accretion), and influences offshore and underwater structures.

Challenges in the project include uncertainties about interactions of turbines with the environment, the limited full-scale environmental surveys, and the difficulty of acquiring data to calibrate and validate numerical models.

Christelle has been on one of the four data-collection trips to the Banks Strait on the AMC vessel *Bluefin* in March 2018. Most of the time, the weather was pretty rough!

Bluefin in rough weather in the Banks Strait
(Photo courtesy AUSTEn Project

PhD Project

The objectives of Christelle's PhD project include:

- Investigate the ability and sensitivity of sediment transport models (2D/3D) to characterise high tidal energy sites.
- Explore sediment measurement methods to determine the best compromise between cost and time with model accuracy.
- Apply the models to study the hydrodynamics and sediment transport in Banks Strait.
- Investigate the interactions between tidal-energy converters (TECs) and the sediment processes, for various seabed and array scenarios.

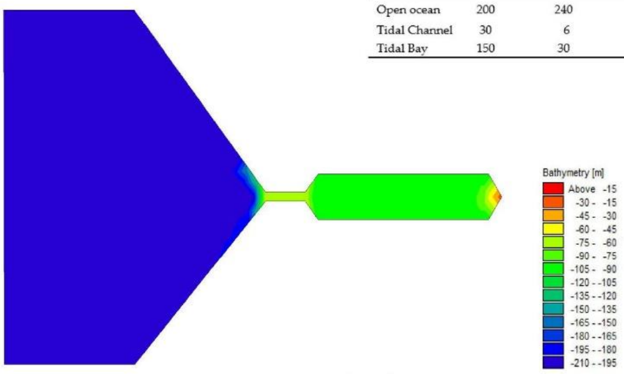
The method started with a literature review, followed by the study of an idealised theoretical channel, then study of the Banks Strait itself and, finally, defining guidelines and methods for TEC developers.

Idealised Theoretical Channel

An idealised theoretical channel comprising an open ocean, a tidal channel and a tidal bay was created based on Yang, Z.Q. et al. (2013), Modelling tidal stream energy extraction and its effects on transport processes in a tidal channel and bay system using a three-dimensional coastal ocean model, *Renewable Energy*, **50**, 505–613.

GEOMETRY OF THE DOMAIN

Domain	Length (km)	Width (km)	Depth (m)
Open ocean	200	240	200
Tidal Channel	30	6	60
Tidal Bay	150	30	100



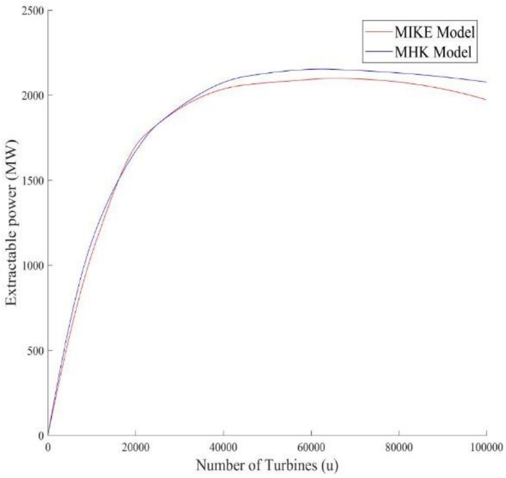
Idealised channel
(Image courtesy Christelle Auguste)

Christelle set up Yang et al.'s model with the same parameters, i.e. a turbine diameter of 10 m at a hub height above the sea bed of 10 m. Five cases were analysed with 1, 2, 5, 6 or 9 turbines in each cell of the tidal channel. The power generated by a turbine is given by

$$P = \rho C_T A_b \overline{U}^2$$

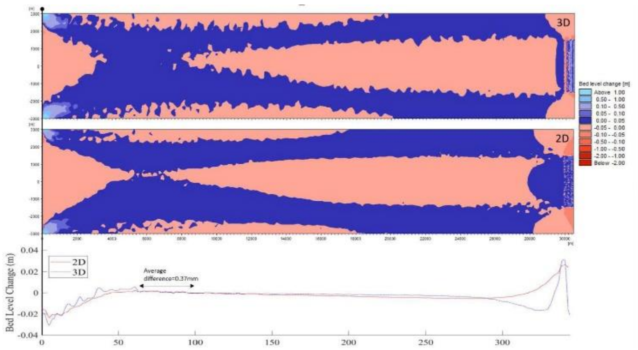
where ρ is the density of water, C_T the turbine drag coefficient (Yang et al. used 0.5), A_b the area swept by the turbine blades, and $\overline{U}$ the depth-averaged current speed.

Yang et al. used the MHK (marine and hydro-kinetic) model with 1140 cells in the tidal channel, where Christelle used the MIKE 21 model with 10855 cells. Her results for power extraction were very close to Yang et al.'s.



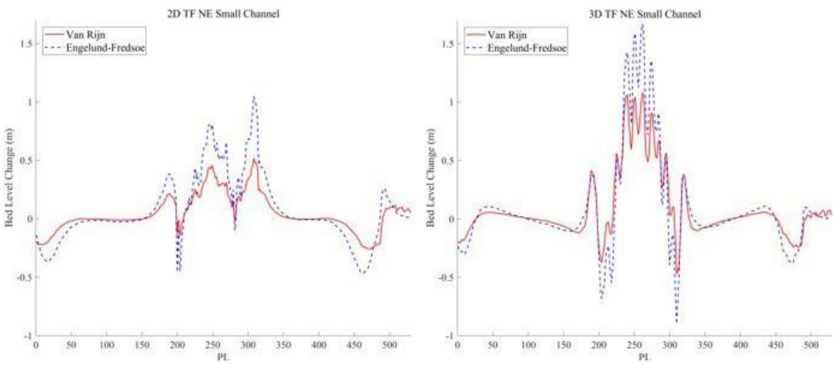
Validation of idealised channel model and extractable power
(Graph courtesy Christelle Auguste)

Other validations of the MIKE model included channel fences, the tidal farm, seabed level changes and their spatial extent.



Bed level change and spatial extent using MHK model
(Diagram courtesy Christelle Auguste)

Two sediment-transport formulas (due to van Rijn, and Engelund and Fredsøe) were also used to evaluate bed level changes for several tidal ranges for both 2D and 3D cases in the tidal channel. Differences of 1.9 were found between the Engelund and Fredsøe and Van Riijn models. The Engelund and Fredsøe model in the non-equilibrium condition was sensitive to changes in current speed, suggesting that small errors in this parameter could lead to significant error in bed level change.

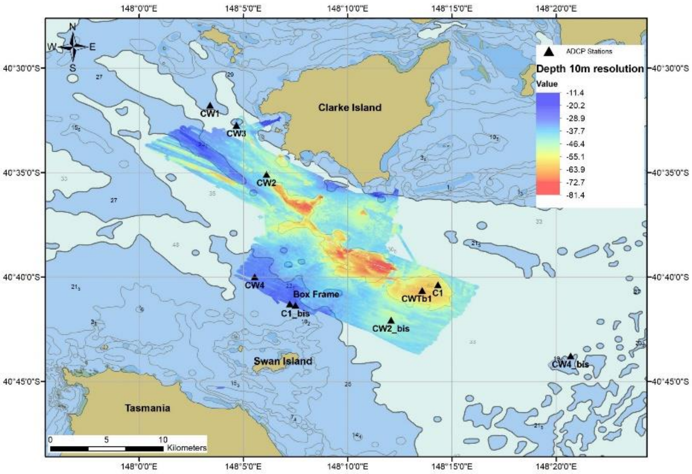


Bed level change using formulas
(Graphs courtesy Christelle Auguste)

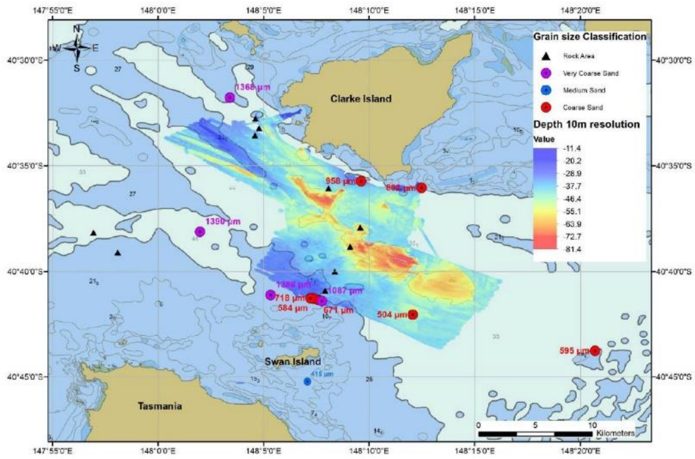
Overall, the validation of the idealised theoretical channel model provided a benchmark for the interaction of tidal-energy converters (TECs) on sediment transport. It was found that MIKE 21/3 flow model can be used for tidal energy extraction modelling. The 2D model seems sufficient to assess behaviour of sediment dynamics away from the tidal farm, but the 3D model using the bottom velocity for sediment transport rates is needed for a more accurate result in the tidal farm itself. Beyond 100 turbines, the impact of TEC arrays become significant.

Data Collection in the Banks Strait

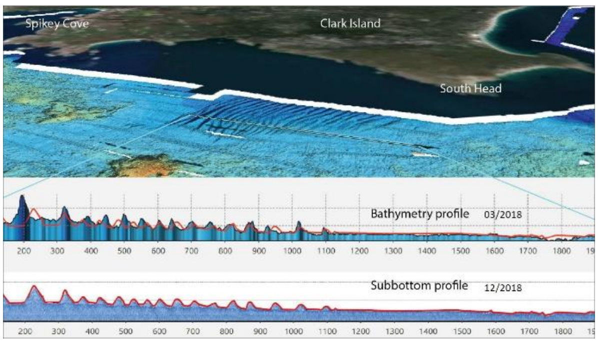
The four data-collection trips to the Banks Strait on board *Bluefin* and other vessels used a number of collection devices, including an ADCP (acoustic doppler current profiler), penetrometer, sediment traps, an optical sensor/LISST (laser in-situ scattering and transmissometry), sub-bottom profiler, and grab sampler. Here Christelle showed the locations of the sampling stations and some of the data collected.



ADCP sampling locations in the Banks Strait
(Diagram courtesy Christelle Auguste)



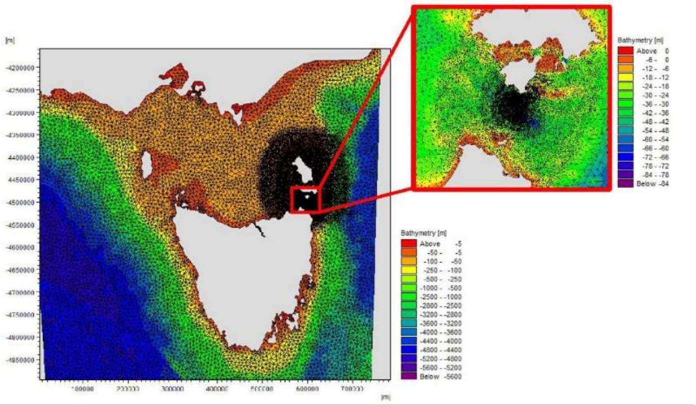
Sediment grain size classification in the Banks Strait
(Diagram courtesy Christelle Auguste)



Bathymetry and sub-bottom profile in the Banks Strait
(modelling shown in red)
(Diagram courtesy Christelle Auguste)

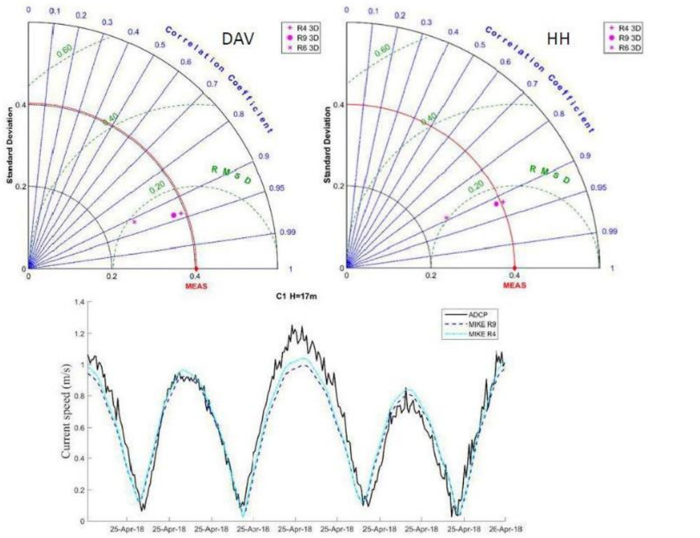
Numerical Modelling

Following collection of the data from the Banks Strait, the task of numerical modelling came next. A mesh was set up around the whole coast of Tasmania, with a spacing of nodes of 50 m in the Banks Strait and 20 m in the area of the turbine farm.



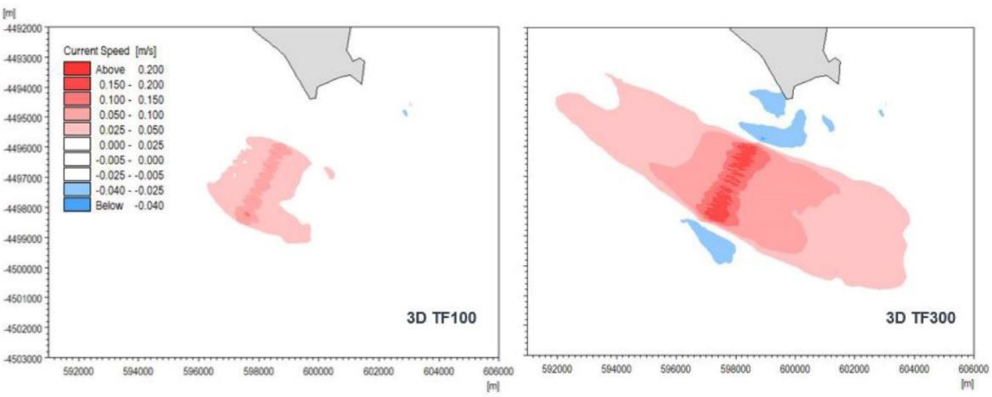
Numerical mesh model
(Diagram courtesy Christelle Auguste)

The model was run for a 35 day simulation, and the model was validated against the collected data. Here Christelle showed a number of validation results for 2D and 3D models. It was pleasing to see correlation coefficients generally in the range of 0.90–0.95, indicating good correlation of the model results with collected data.

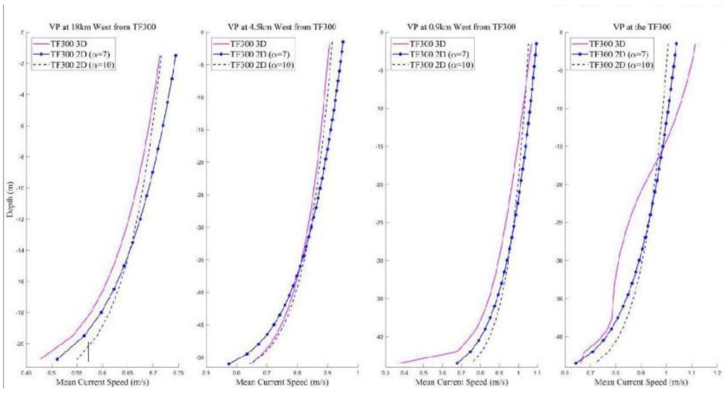


Calibration of 3D model against ADCP data for depth average velocity (DAV) and hub height (HH)
(Graphs courtesy Christelle Auguste)

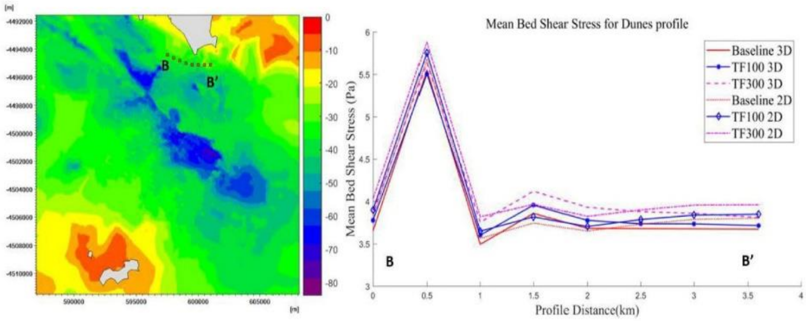
Influence of the Tidal Farm
Having validated the model, it was then run to check the influence of tidal farms of various sizes on the environment.



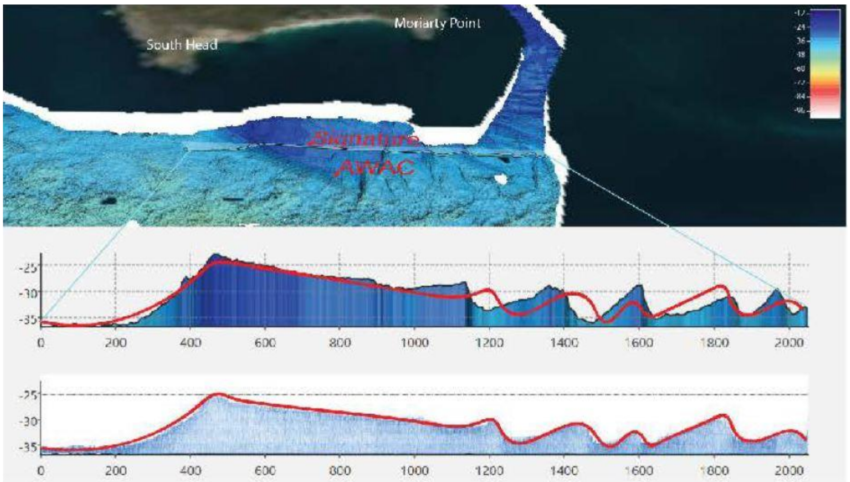
Change in magnitude of current speed at the hub height between baseline and case with tidal farm for 100 turbines (L) and 300 turbines (R)
(Diagrams courtesy Christelle Auguste)



Velocity profiles at various locations west of a 300 turbines farm
using 2D and 3D simulations
(Graphs courtesy Christelle Auguste)



Mean bed shear stress for the sand dunes profile B–B' in the Banks Strait
(Diagrams courtesy Christelle Auguste)



Sand dunes profile B–B' and modelling (in red) in the Banks Strait
(Diagrams courtesy Christelle Auguste)

In general, for turbine farms of more than 100 units, the environmental impact becomes significant.

Conclusion

This investigation is part of the AUSTEn project which is laying the groundwork for the commencement of tidal-energy production in Australia. The existing technology and installations around the world have been surveyed and an idealised theoretical model has been created and validated. The Banks Strait has been surveyed to collect data on the local tidal environment, and a numerical model created and validated against the data. The model has then been run to check the influence of tidal farms of varying sizes on the environment and, specifically, on sediment transport. The model will further be used to provide guidelines and methods for developers of tidal-energy converters.

Questions

Question time was lengthy and elicited many more interesting points.

The certificate was subsequently posted to Christelle, and the “thank you” bottle of wine delivered via an eGift card.

Christelle’s presentation was recorded, and is now available to webinar registrants on the Engineers Australia On Demand website.