THE UNIVERSITY of ADELAIDE

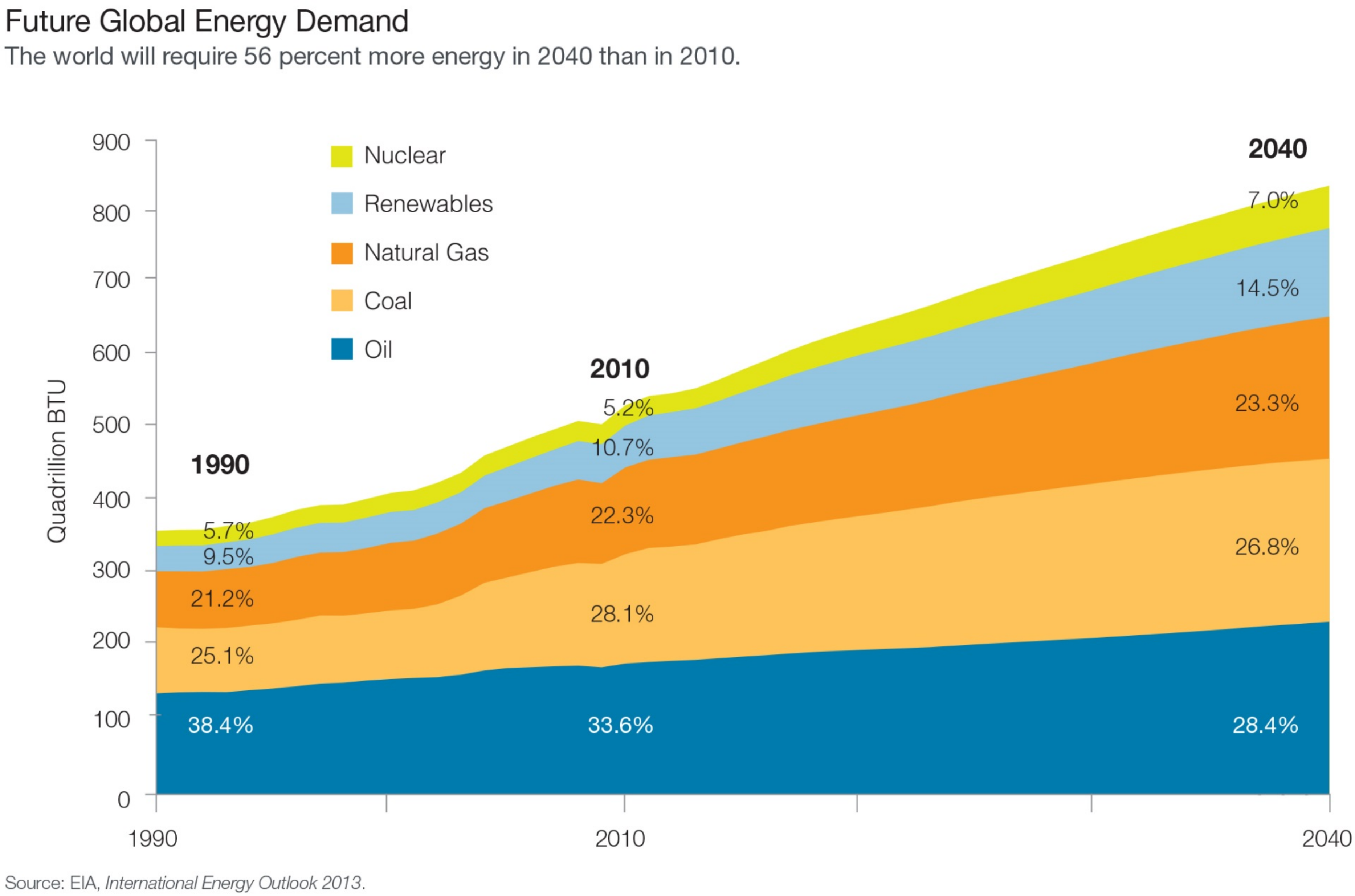
Carnegie wave energy

Fast and effective optimisation of arrays of submerged wave energy converters

Junhua Wu, Slava Shekh, Nataliia Sergiienko, Benjamin Cazzolato, Boyin Ding, Frank Neumann, and Markus Wagner

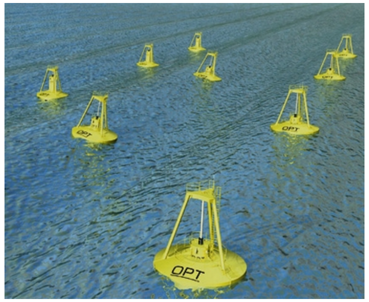
Presented by Markus

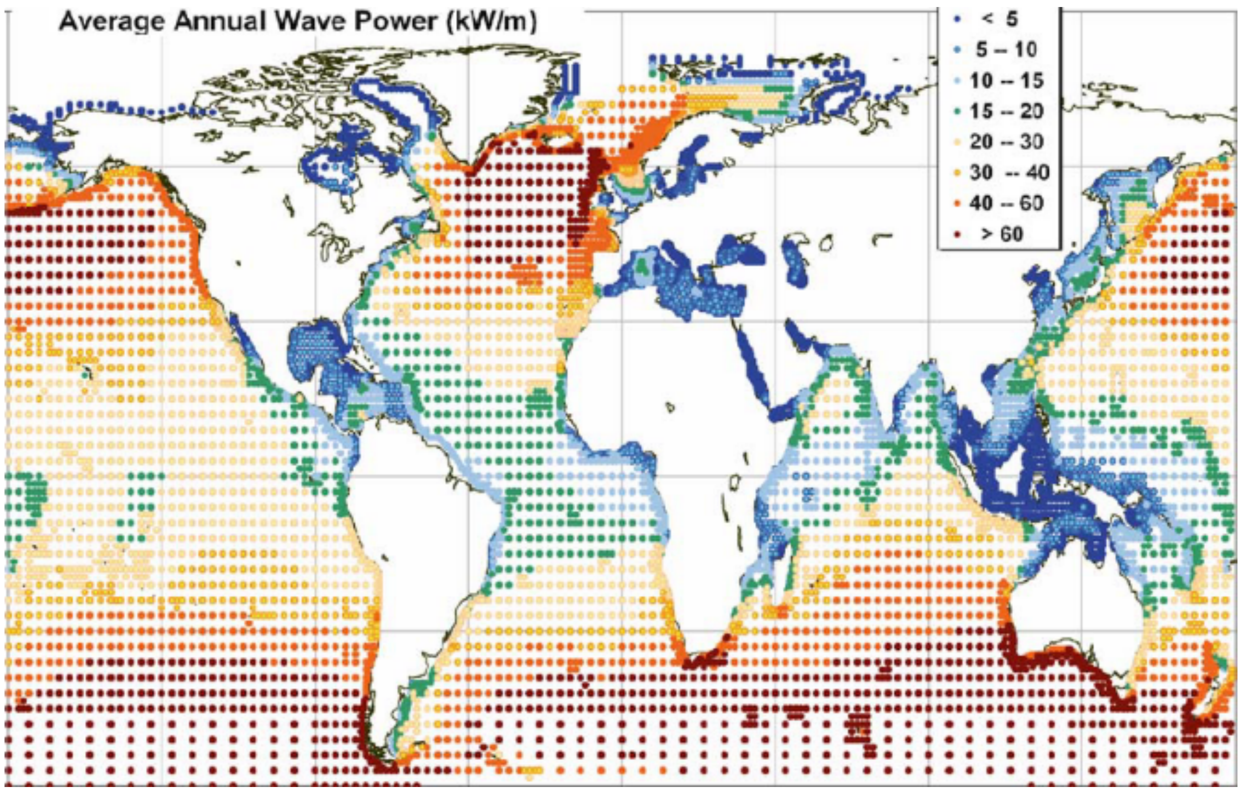
The Need for Renewable Energy



Wave Energy

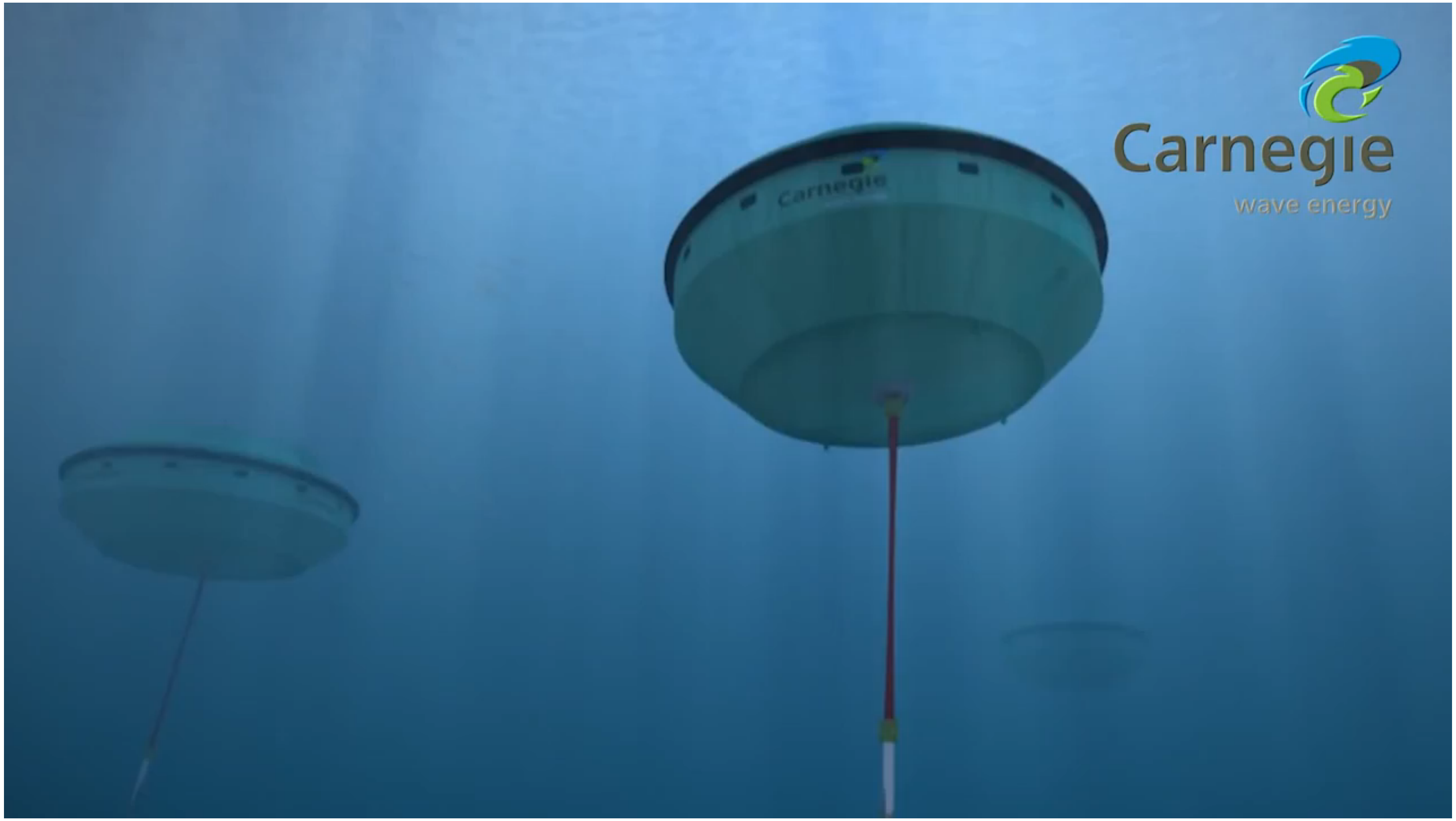
- Wave energy is a widely available but largely unexploited source of renewable energy
- There are dozens of active wave energy converter (WEC) projects exploring a variety of techniques for harnessing wave energy





CETO Wave Energy Converter

- In partnership with the School of Mechanical Engineering, we are considering a wave energy converter (WEC) called CETO
- The CETO system consists of one or more fully submerged buoys



Related Work on Optimisation

Single WEC optimisation

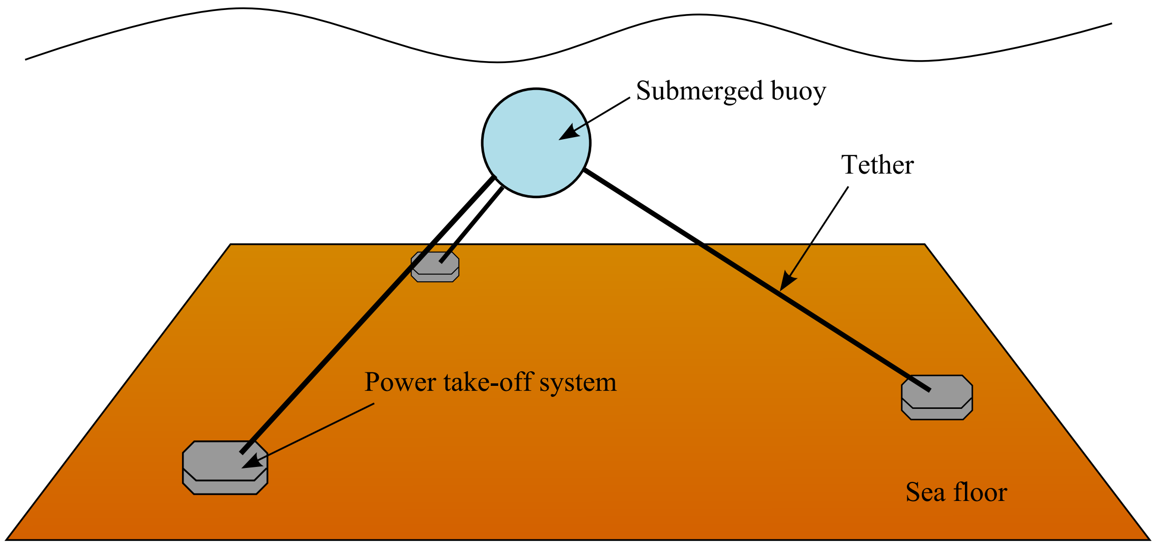
- Ringwood (2004), McCabe (2010) and Hals (2011) optimise various aspects of semi-submerged buoys, such as ***geometry and control***
- Korde (2015) investigates different ***control strategies*** for maximising power absorption of two buoys, one of which is fully submerged

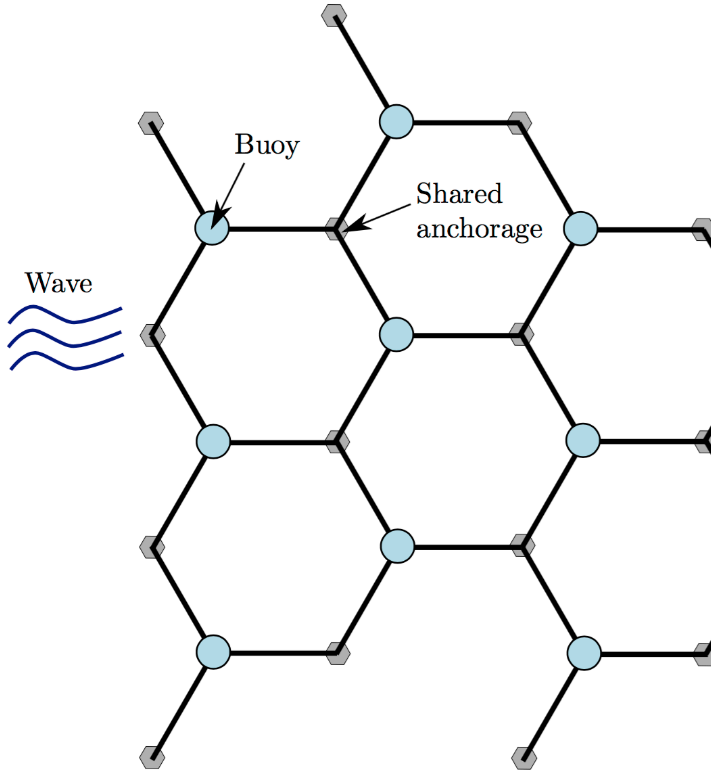
WEC arrays and their optimisation

- Cruz (2009) and Weller (2010) explore the effect of various factors on ***array performance***, including device spacing and array layout
- Fitzgerald (2007), Child (2010) and Snyder (2014) optimise arrays of ***semi-submerged WECs***

There is a lack of research on optimising arrays of fully submerged WECs

The CETO Model





Advantages

- Invisible from the shore
- Higher survival in storm conditions
- Hydrodynamics allow 2 times more power to be absorbed from surge motion (e.g. via three-tether or asymmetric mass)

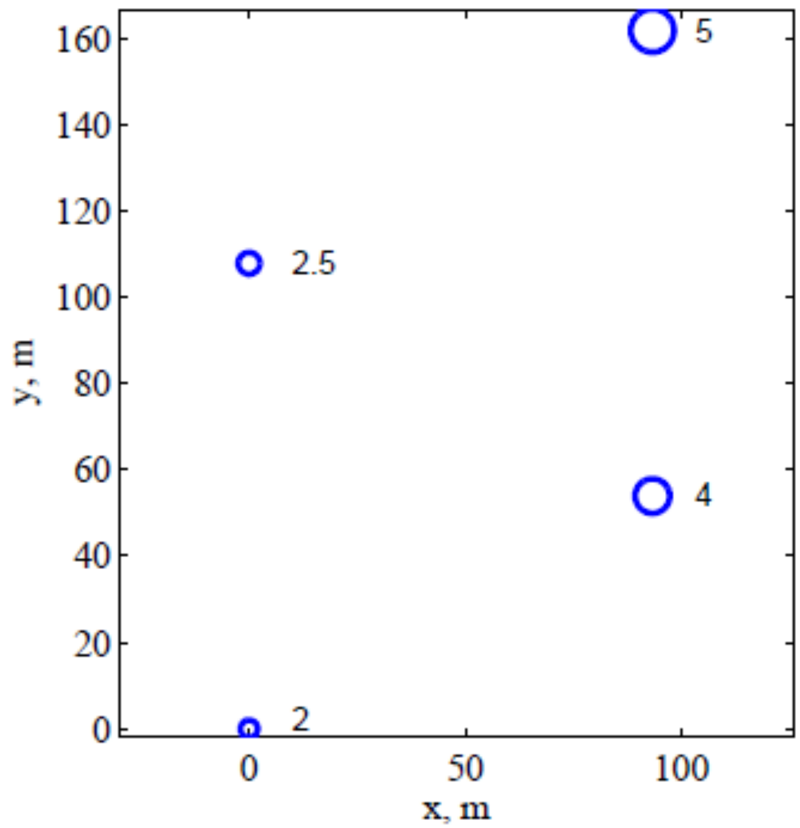
Optimisation Problem

- The variables of the CETO model lead to an optimisation problem: **What is the best combination of buoy radii to use for different array sizes?**

- A solution (configuration) can be represented as: $(r_1, \ldots, r_n)$ e.g. the layout shown is (2, 2.5, 4, 5)

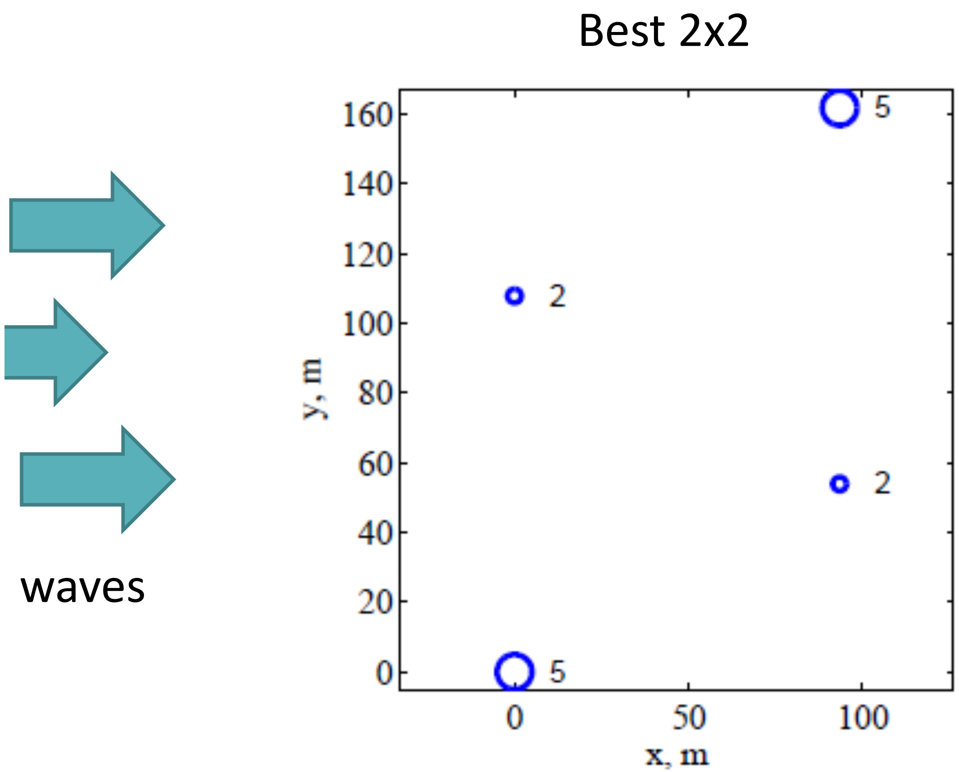
- A solution can be evaluated using the q-factor, which is the ratio of the power absorption of a buoy array compared to the power absorption of the same buoys in isolation

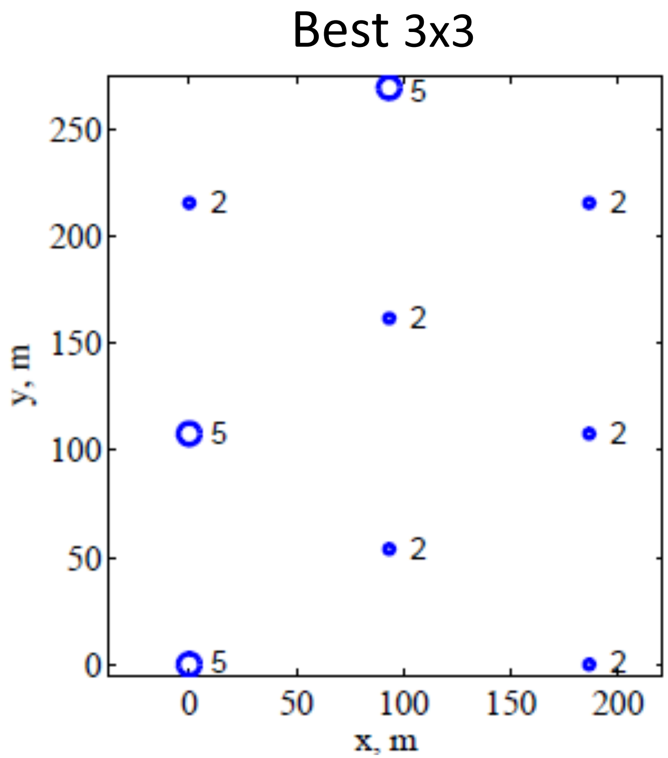
$$q = \frac{P_\Sigma}{N \cdot P_0}$$



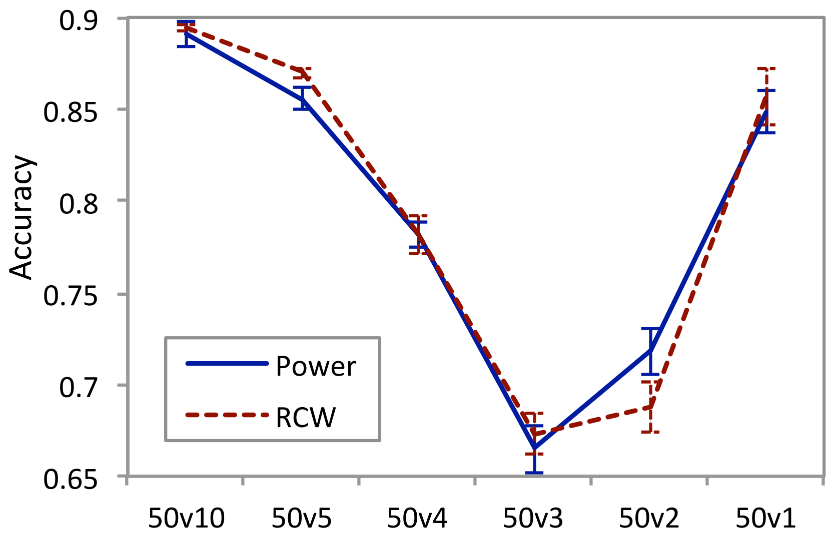
Results for 2x2 and 3x3 Arrays

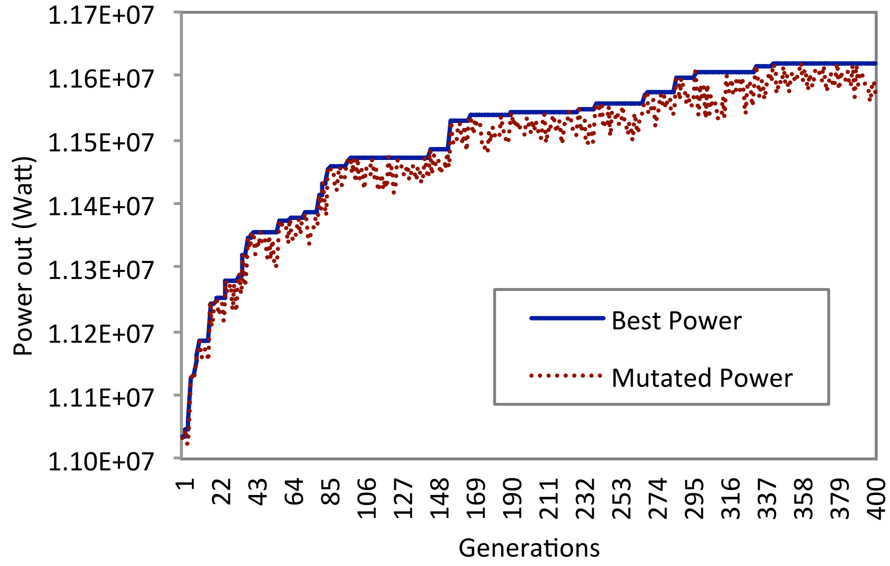
	2x2 Array	3x3 Array
Best (q-Factor)	0.999	0.996
Worst (q-Factor)	0.965	0.933





Speeding up simulations (for non-grid arrays)



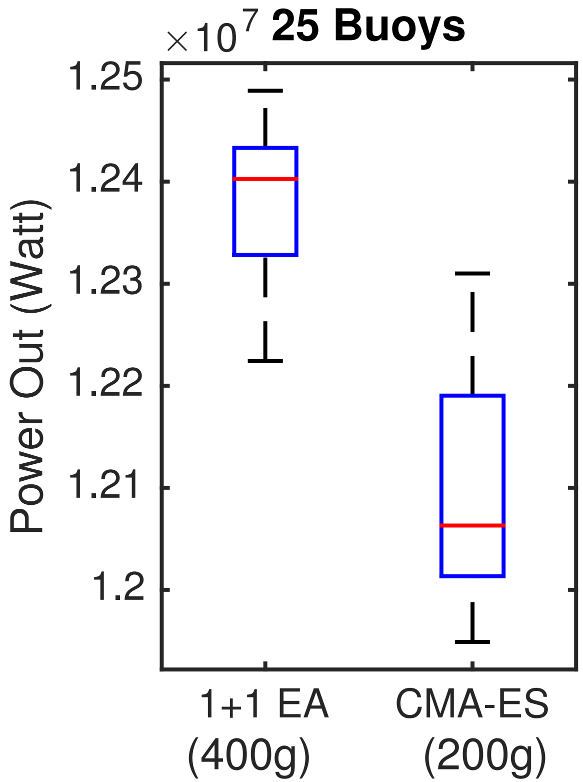


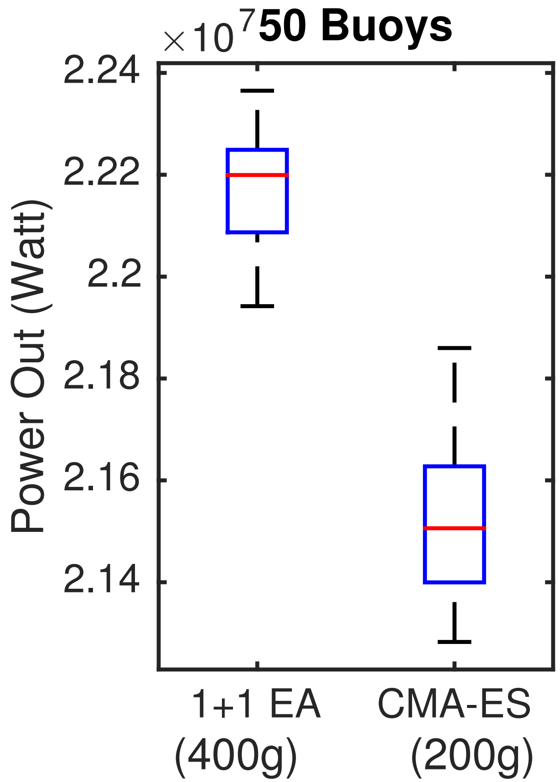
Speed-up by frequency reduction from 2100 minutes to 42 minutes (50 buoys).

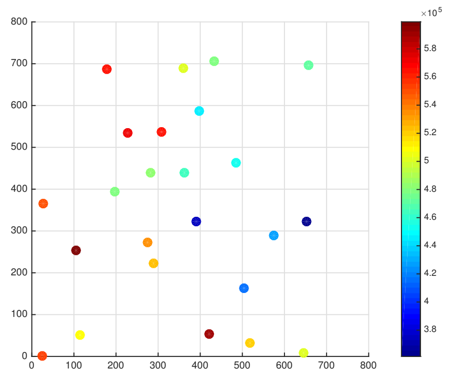
An old computer science trick… ***caching!!!***
Matlab most frequently calls: `integral`, `factorial`, `bessel`.
For a 50-WEC-array, 1 million calls to `integral` are made (90% duplicates). ➔
Caching reduces the runtime by 85%.

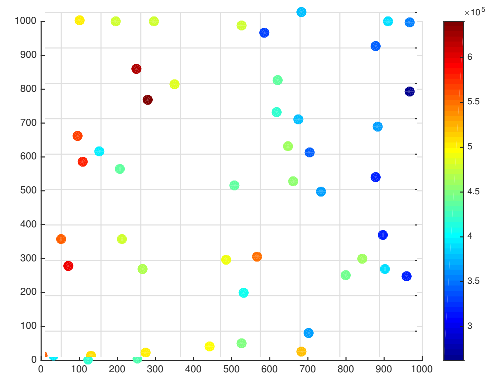
Now: runtime 6 minutes (factor <u>350</u>).

Non-grid-arrays: (2+2)-CMA-ES vs (1+1)-EA





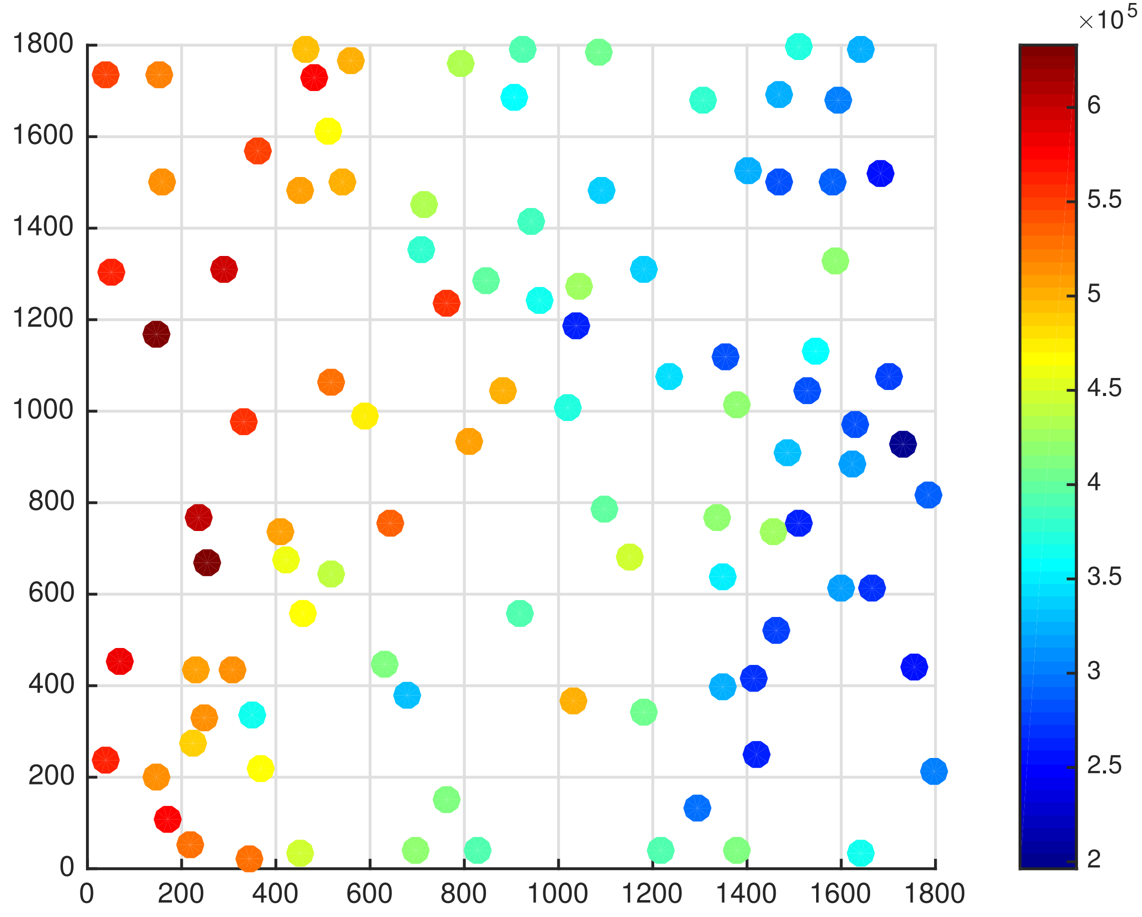




→ Tuning in the end with CMA-ES is possible, though.

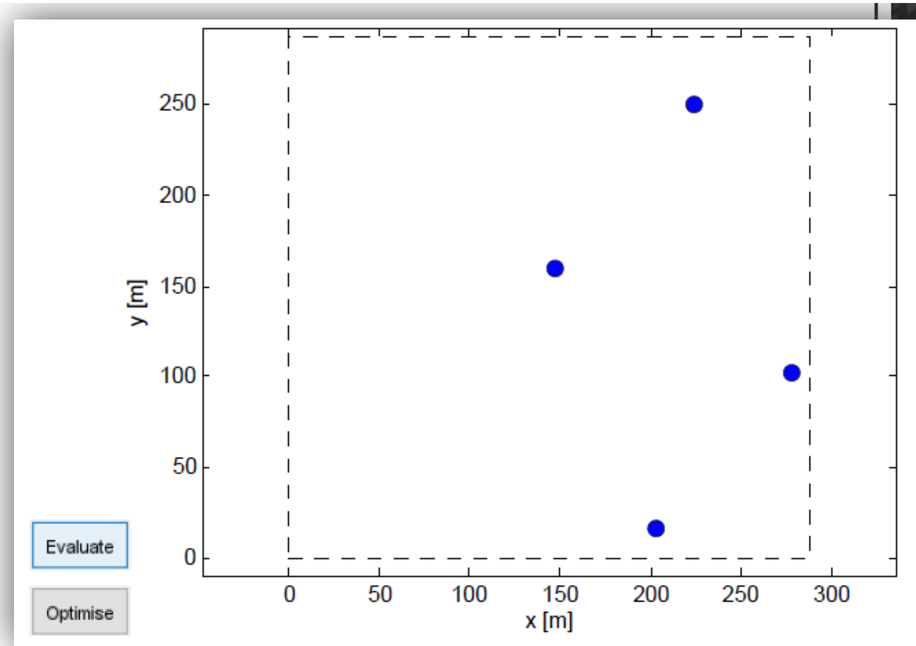
Drawbacks (example for n=100)

Computation time: 8 CPU days vs. 7 CPU years



Algorithms: local optima not exploited
Speed-up: simplification not adequate

Summary so far & Next Steps



- Translation to C
- Parallelisation
- Increase in accuracy
- Multi-objective optimisation
  → *PPSN 2016*: 142-fold speed-up while still using 25 frequencies.

Actual next steps

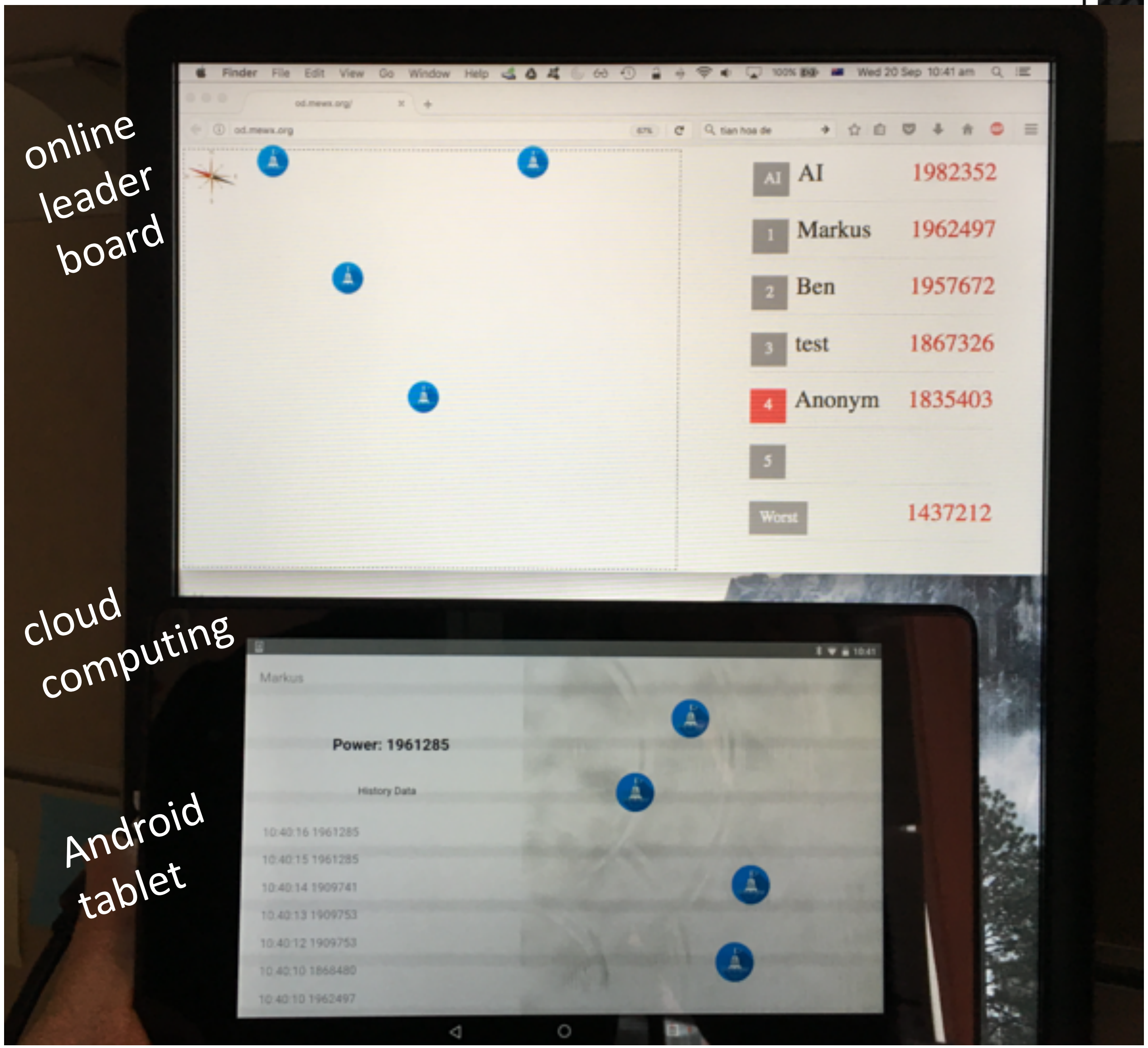
- Wave directions: distribution *(happening now)*
- "mechanical engineering"-analysis of results *(happening now)*
- Carnegie to set up arrays of WECs around Australia *(joint ARC grant happening now)*
- Power-take off-controller optimisation
- Machine learning models to learn the interaction *(happening now)*

Wave Energy: Insights

MS Software Engineering students: Chenwei Feng, Mengyu Li, Yuanzhong Xia
Supervisor: Dr. Markus Wagner

OpenDay/Ingenuity 2017

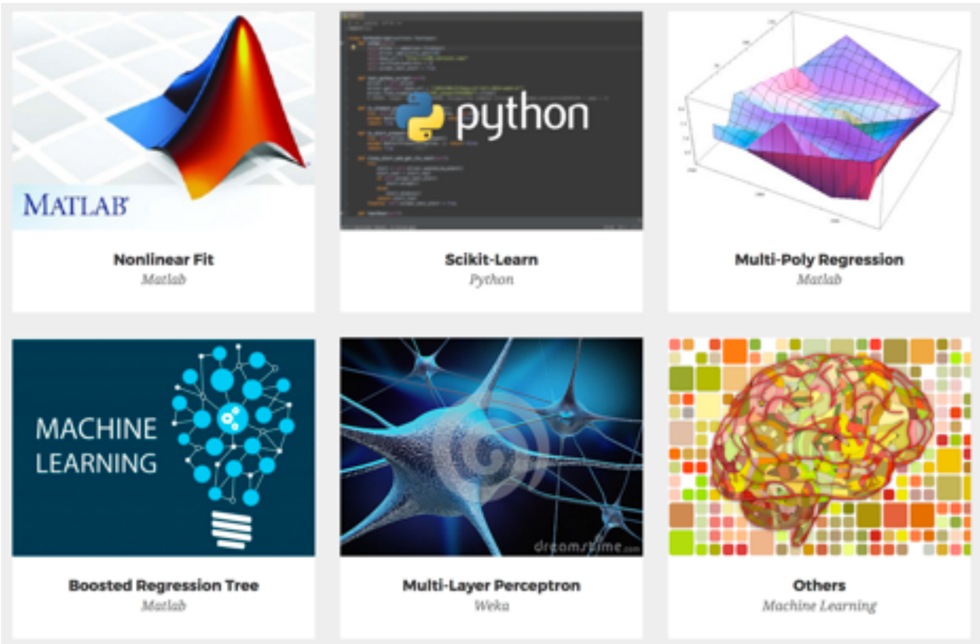
- Over 100 people played the “optimise power output” game using Android tablets at OpenDay 2017
- Leader board: http://od.mewx.org/
- Refined version to be used at Ingenuity 2017 (31 Oct, thousands of attendees)

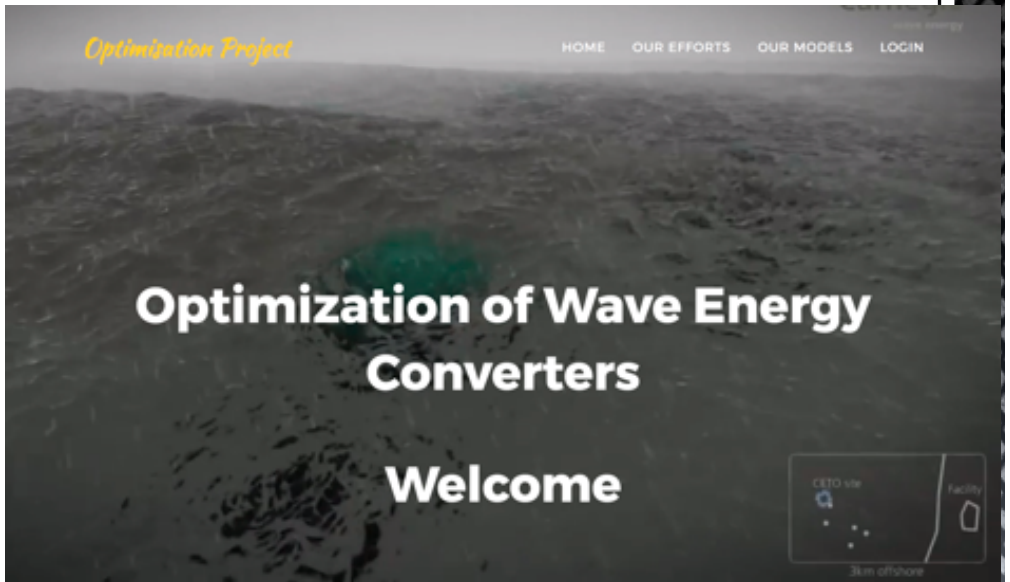


MS Software Engineering
Chenwei Feng, Mengyu Li,
Yuanzhong Xia

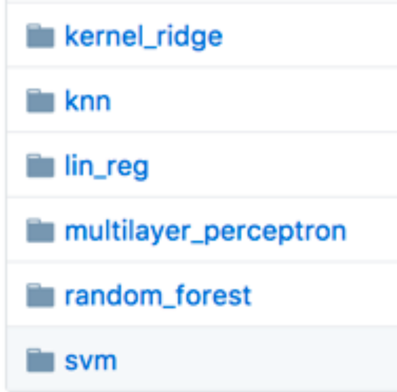
MS Project (2 Semesters)

- Goal: model & predict power output based on farm layout
- Machine learning technology as quick and precise surrogates for Nataliia’s analytical model (frequency domain)
- https://mse.mewx.org
- 2 buoys doable, 4 buoys difficult (imprecise)



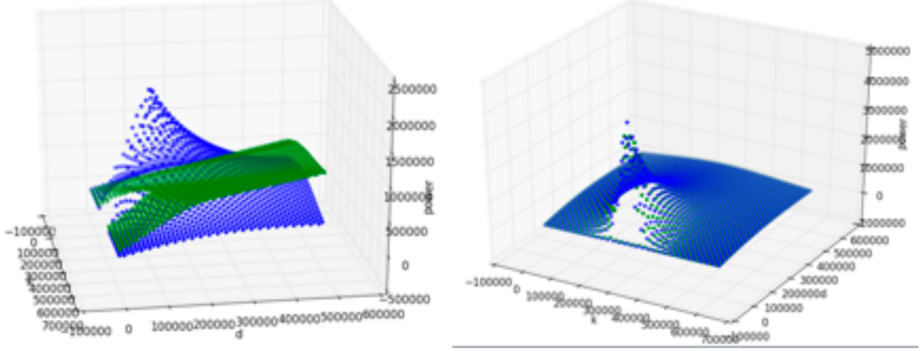


Honours project
Connie Pyromallis

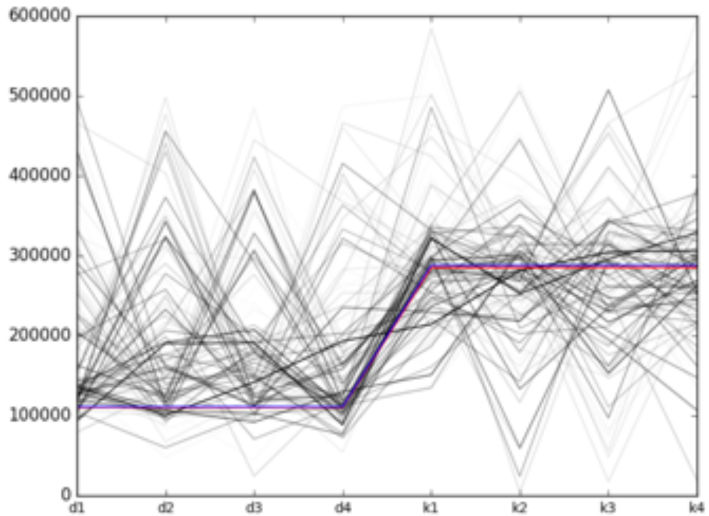


- Goal: model & predict power output based on spring constant k, damper coefficient d
- 4 buoys
- Scikit-learn (Python)
- https://github.cs.adelaide.edu.au/a1668648/HonoursWEC

One setting for all buoys (neural network, random forest)



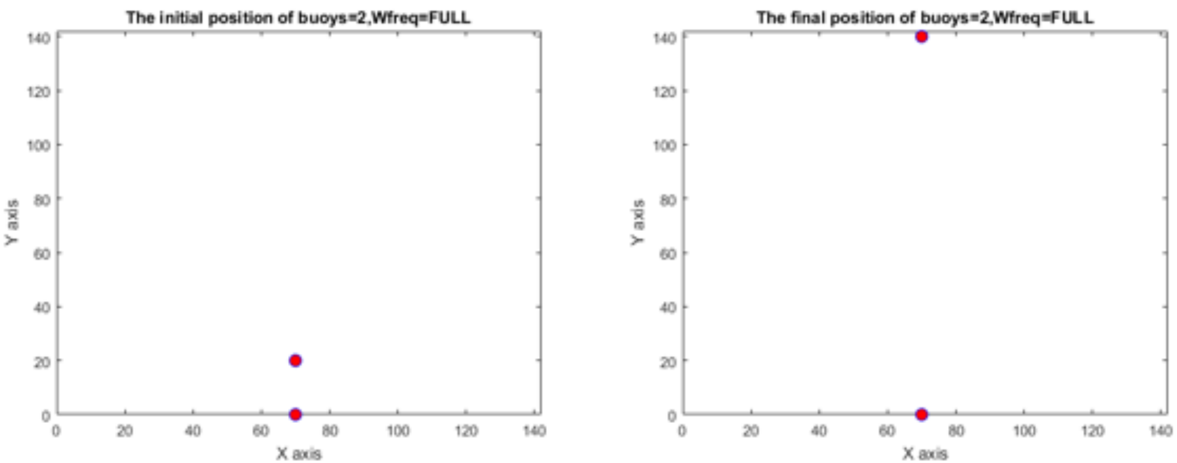
Different settings for each buoy (best 100 settings)



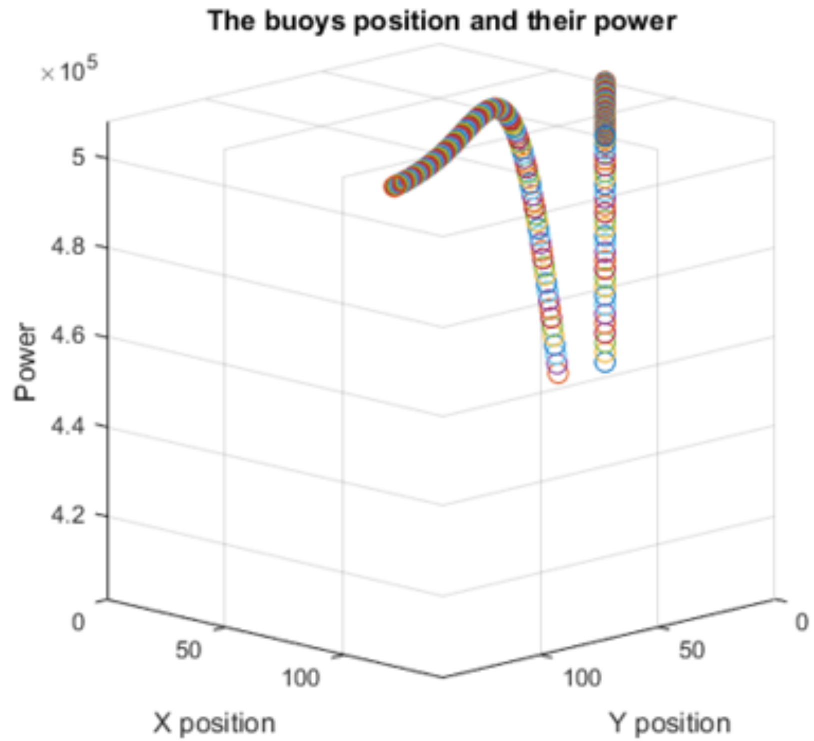
PhD student Mehdi Neshat
MS student Yuanzhong Xia

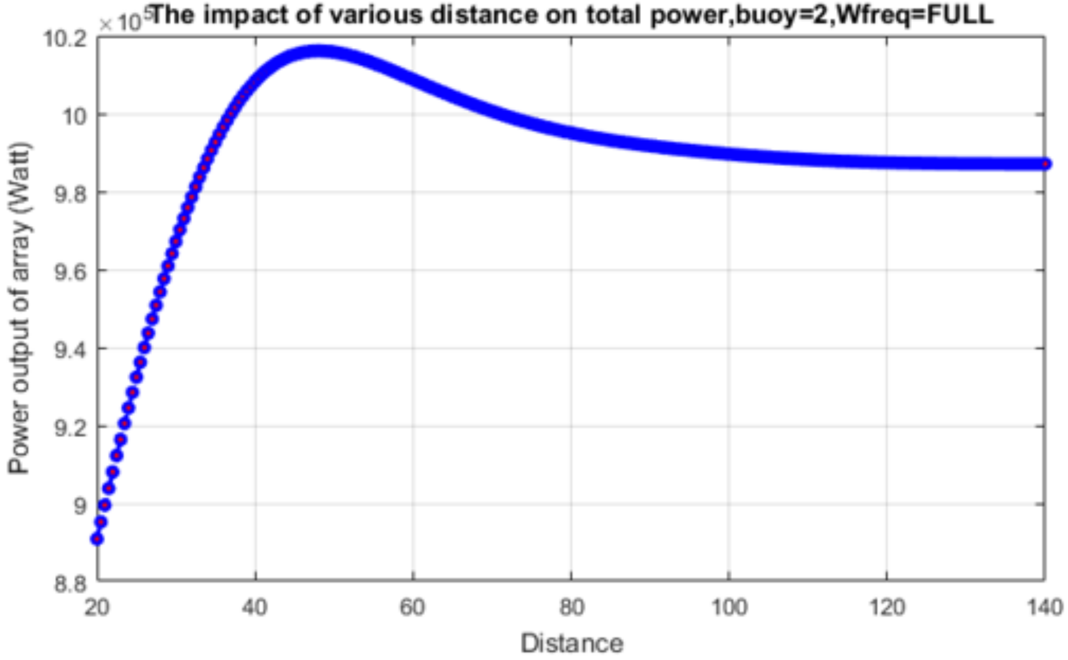
Coming back to those layouts…

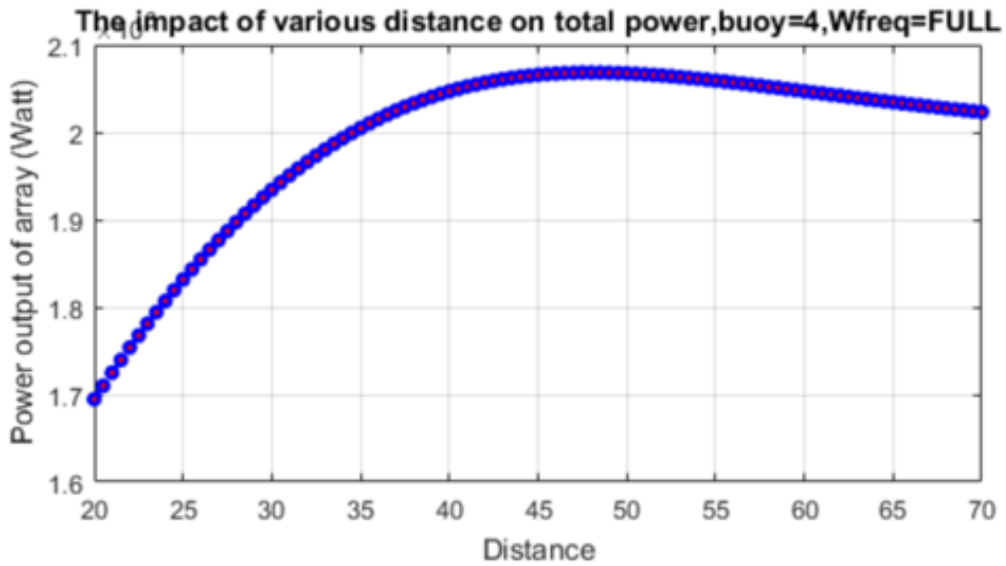
- Educated guess as a reference: What is a good layout? Grid? Linear? Hexagonal?
- Waves come from the left…



And the same for 4 and 9 buoys…







Similar for 4 and 9 buoys…

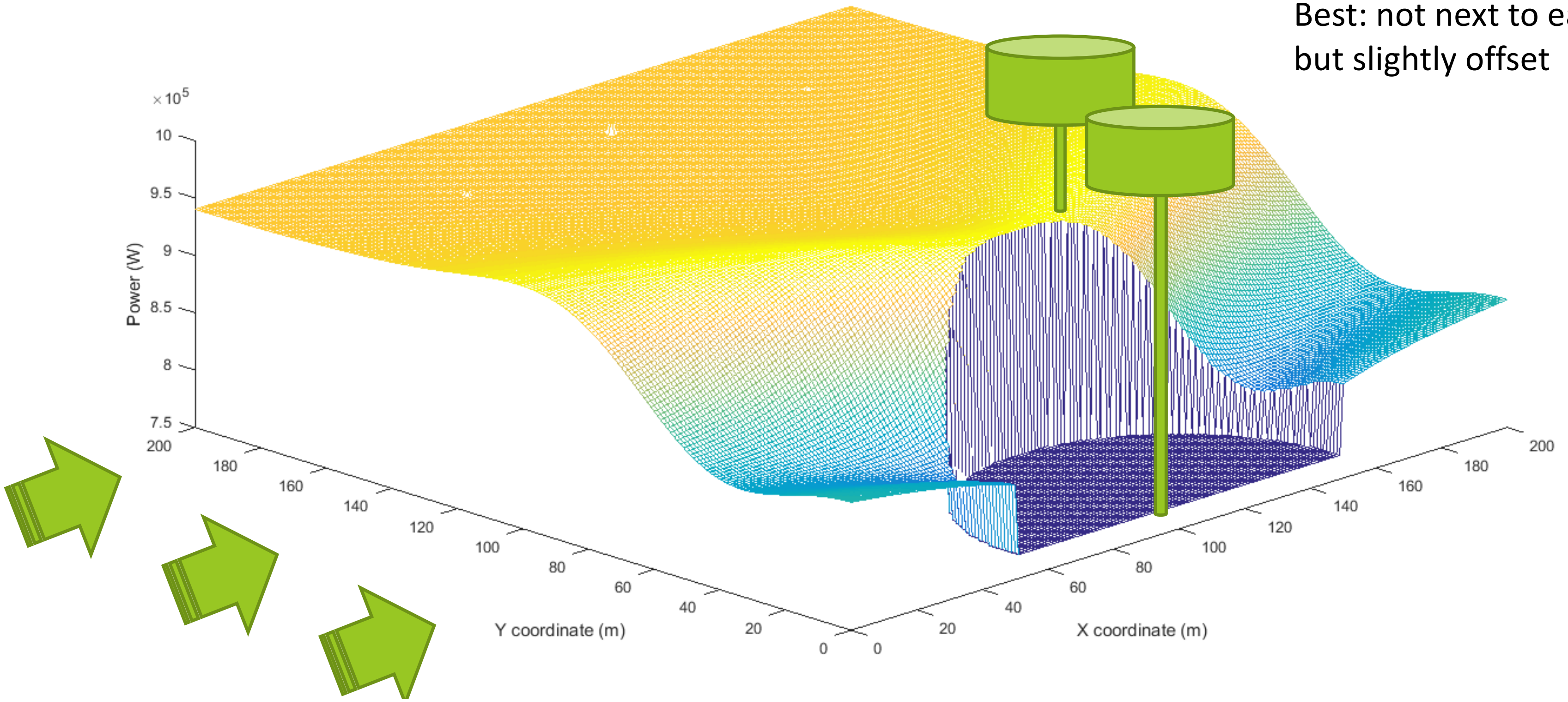
Output of 1 isolated buoy: 4.92e5W

This is 1-dimensional… how about 2D?

2 buoys – Characterisation of effects for optimisation purposes

- Waves come from bottom left, 50m safety distance
- 1st buoy is at (100,0), shown is the wave farm's total power output landscape depending on the 2nd buoy

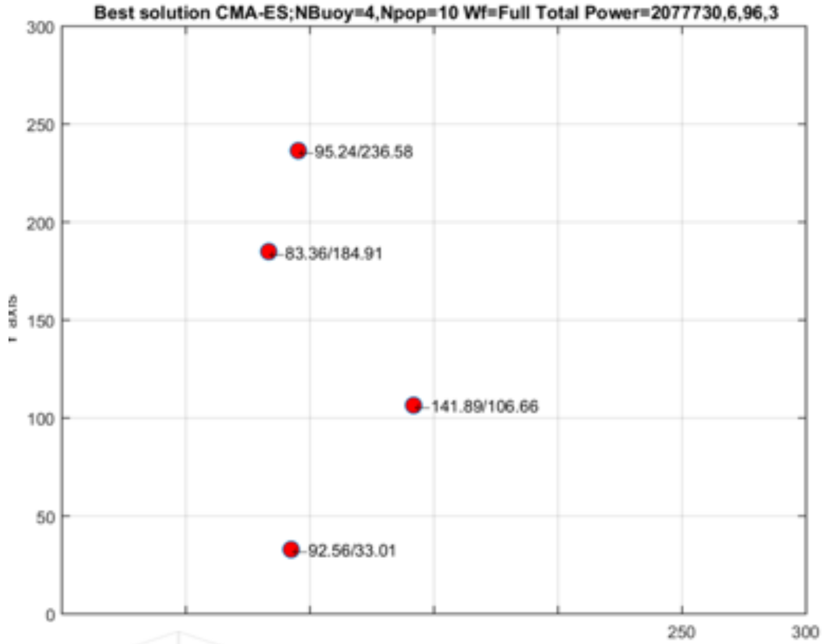
Best: not next to each other, but slightly offset

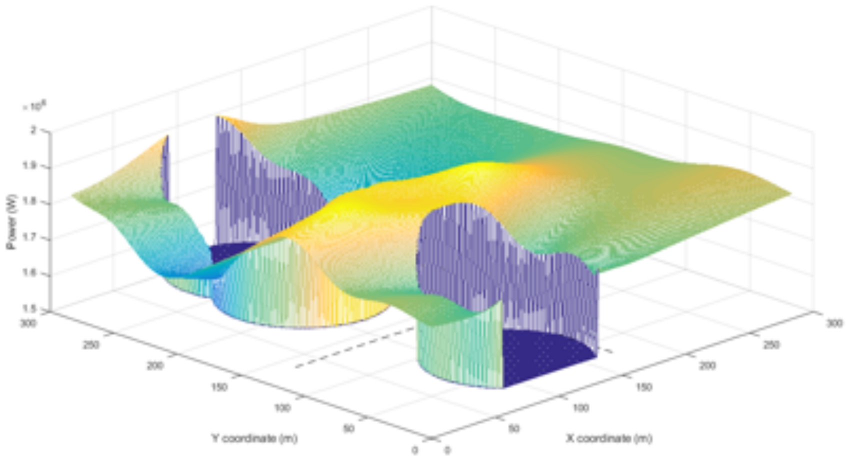


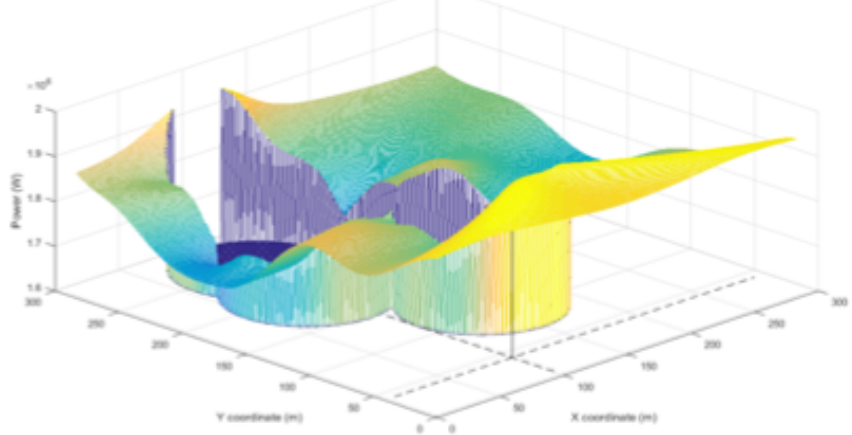
4 buoys

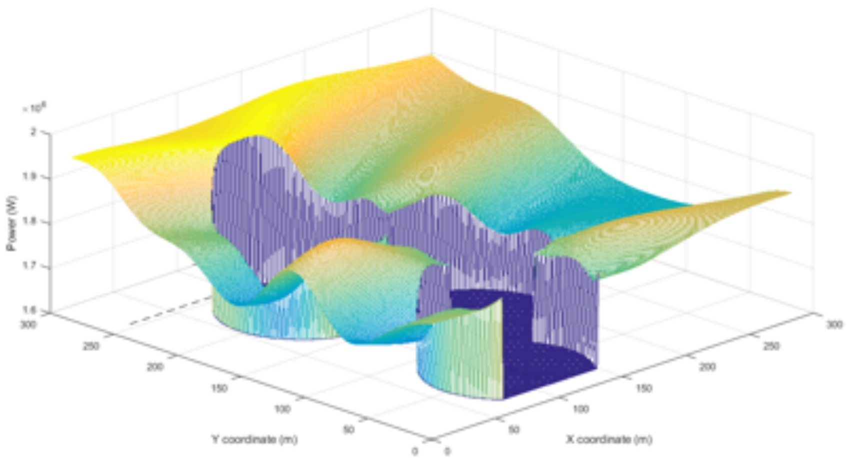
Mapping for each buoy given the other three buoys:

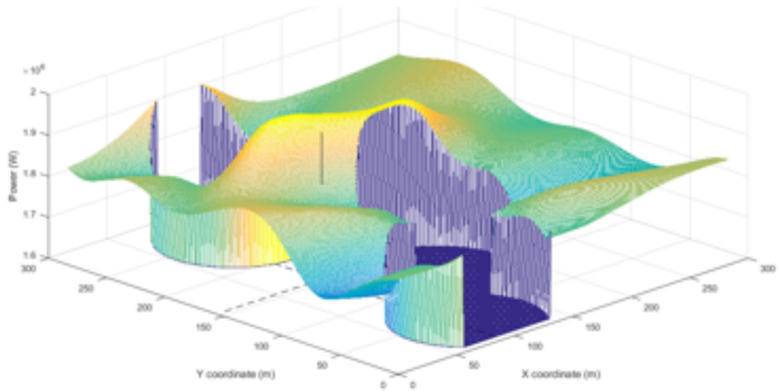
Best ever found:







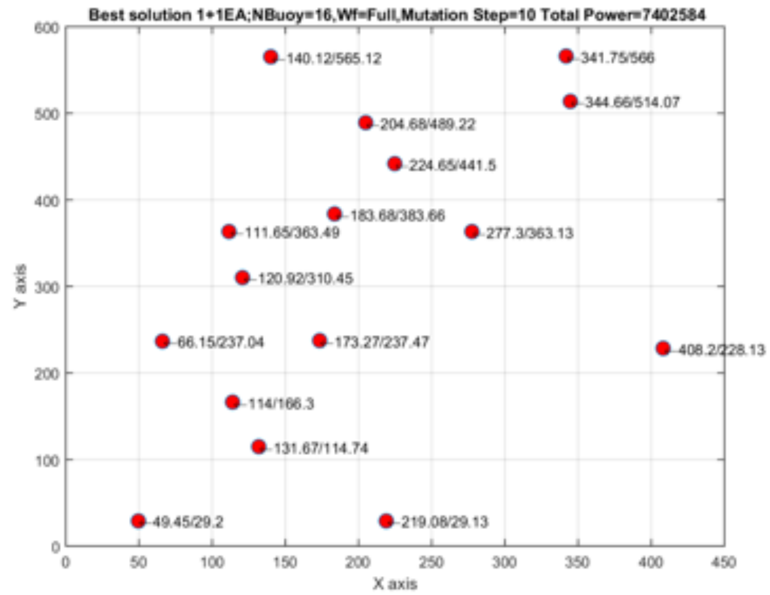




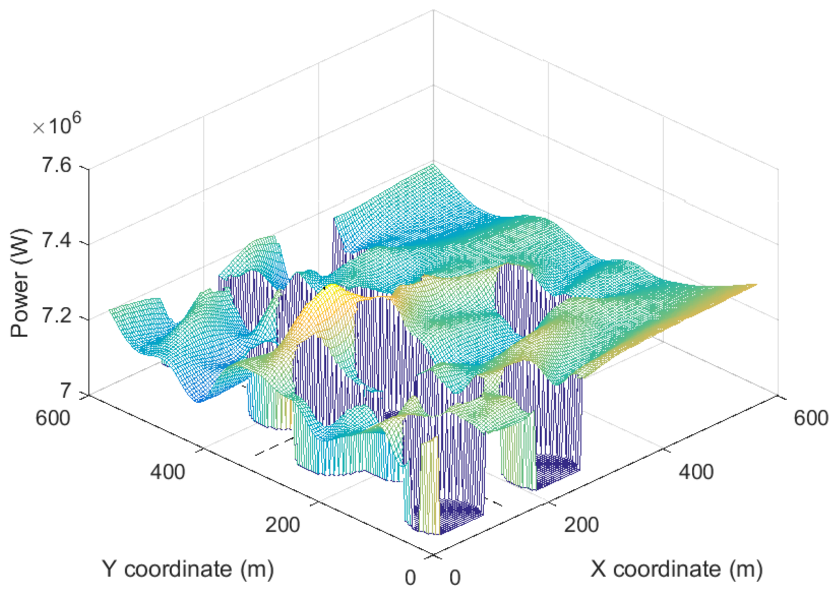
16 buoys

- We see patterns…

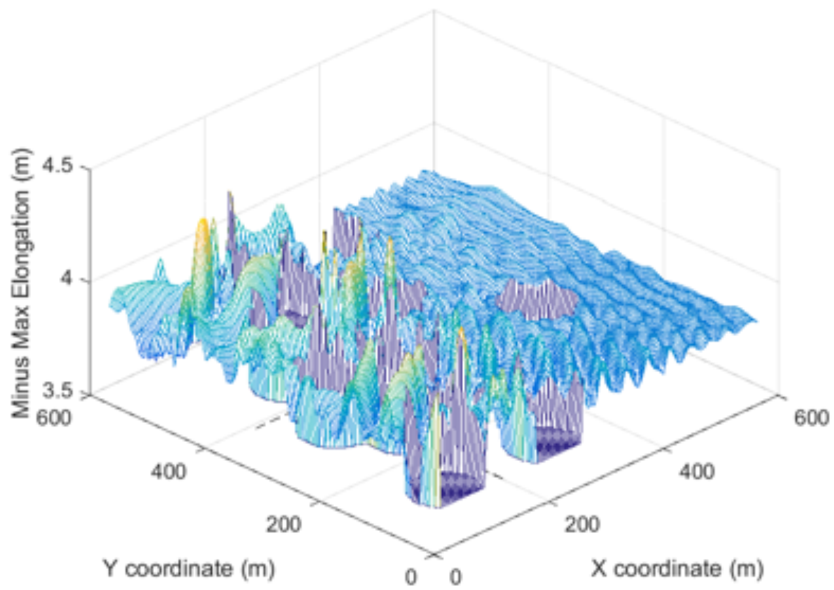
Best ever found:



Farm's power, with omitted buoy's location as dashed line



Max tether elongation across farm (arbitrary limit: 3m, here: 4.5m reached)

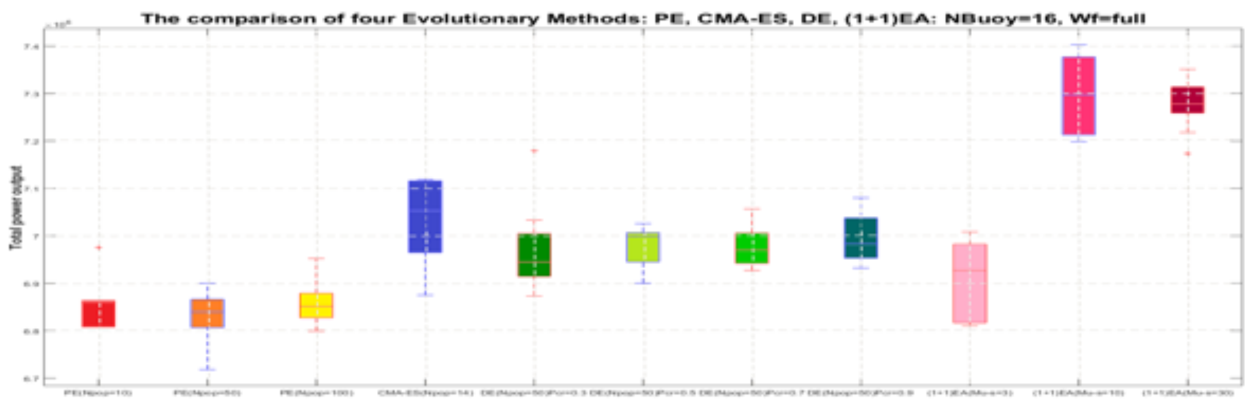


Layout optimisation

- Based on the characterisation, we can design problem-specific algorithms. Why is this important?

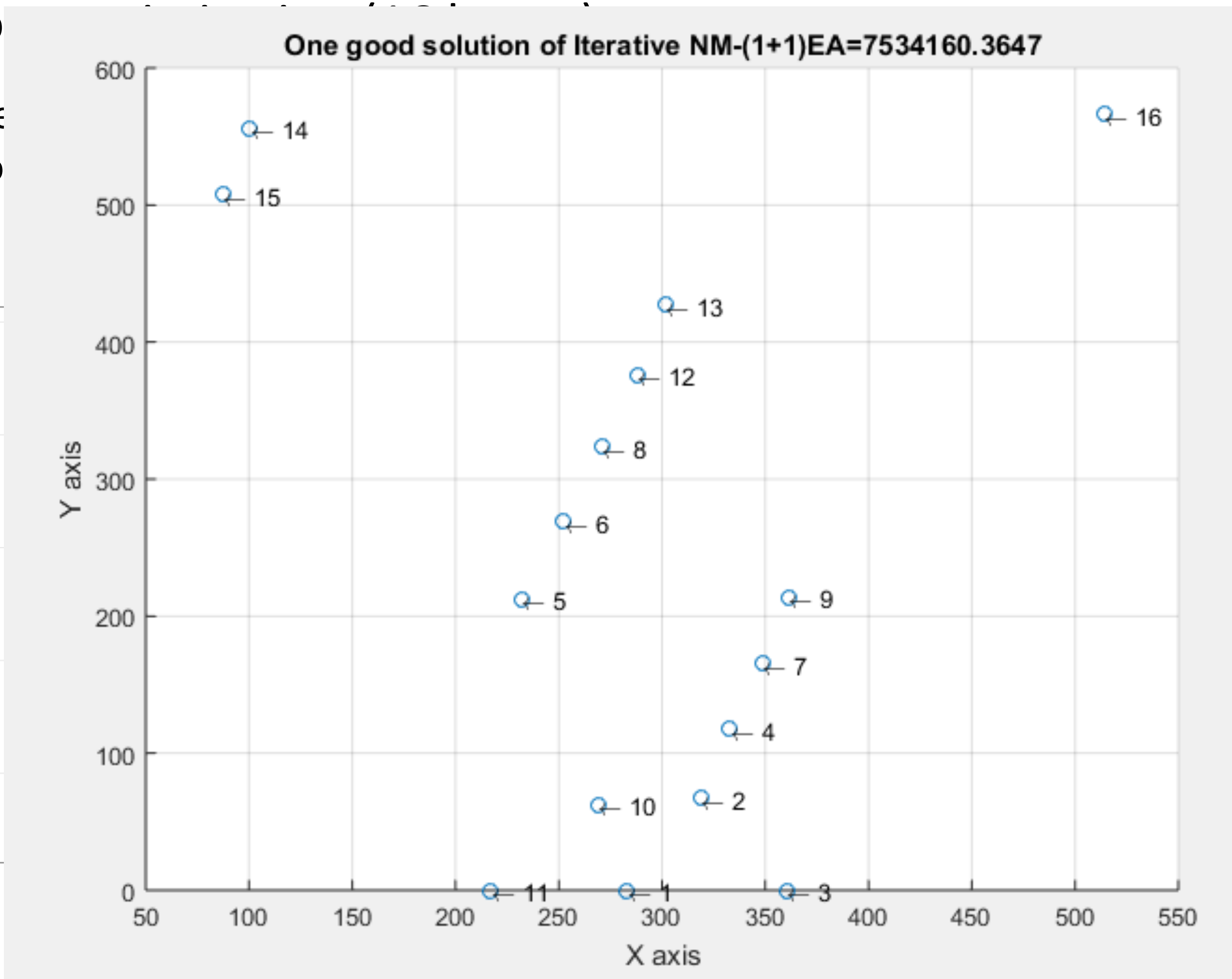
4 buoys: max output is very similar across approaches (scale not visible)

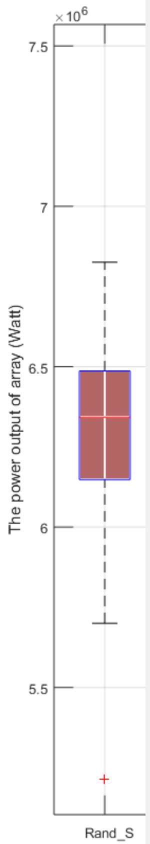
16 buoys: +5% for the rightmost two custom approaches



Layo

- Base
  algo





http://cs.adelaide.edu.au/~markus/

The slides will be made available today.

Markus Wagner

markus.wagner@adelaide.edu.au