Using *Big Data* in the pursue of a sustainable and safe maritime future

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WISE kick-off symposium
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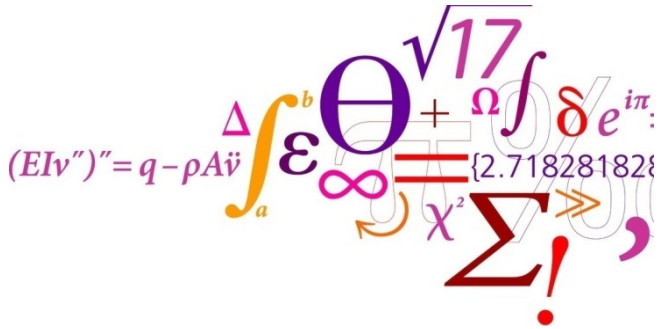
DTU Mechanical Engineering
Department of Mechanical Engineering



Outline

1. Introduction
2. An overview about recent and ongoing projects at DTU Mechanical Engineering
   A. Sea state estimation (SSE) using multiple observations platforms
   B. Evaluation of retrofits for increased fuel efficiency
   C. Voyage optimization benefits for different shipping stakeholders
3. Final remarks

Prologue

NB: The research projects target goals 9, 12, 13, 14, and 17

Introduction

Using **Big Data** and ***machine learning***…

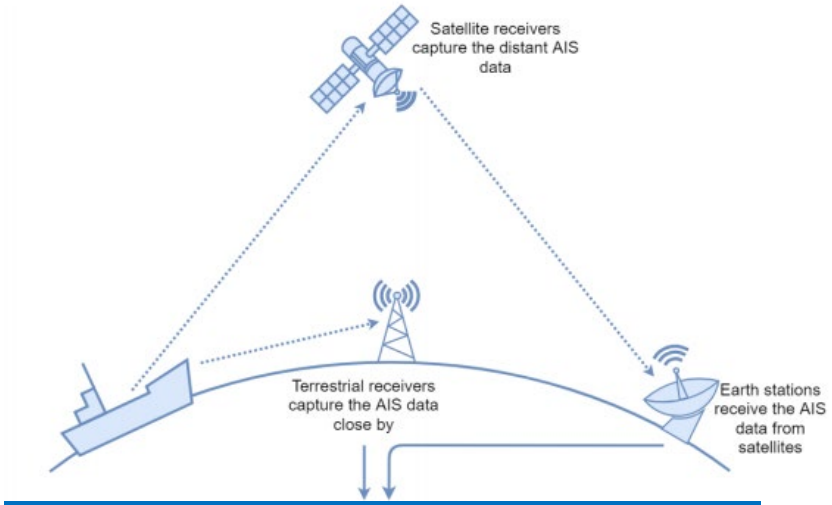
To ensure **SAFE**, **GREEN** and **EFFICIENT** marine design and operations! Examples are,

- **Ships in transit, adverse weather** with a focus on safety (e.g., the of decision support system)
- **Crane and tow operations** during installation and maintenance of windfarms, fish cages, etc. (re operational windows, control systems for DP)
- Vessel **performance monitoring** (re added-wave resistance)
- For **'black box' purposes** (re accidents and other post-event investigations)
- **Improvement** of large-scale, spectral wave models leading to better weather forecast, and more accurate wave hindcasts (re the need for calibration, data assimilation)
- Besides, wave measuring is important to understand the mechanisms of surface water mixing and air-sea fluxes (re **climate changes**!)

Introduction

Using Big Data and *machine learning*…

This presentation gives highlights about three (research) projects where the use of large amounts of data is fundamental!

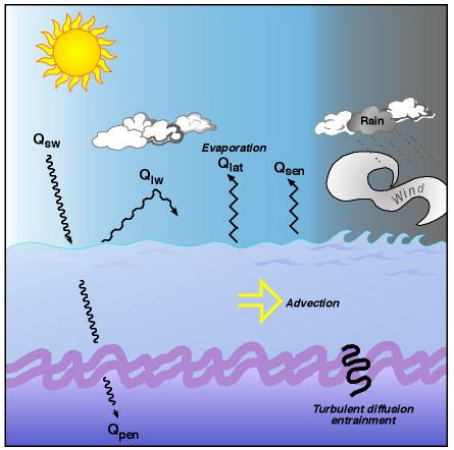


Sea state estimation based on data from multiple observation platforms

Why do we want to *measure* waves?

- Because waves are the fundamental driver of most of the processes* we are concerned about as maritime engineers, naval architects, or ocean scientists.

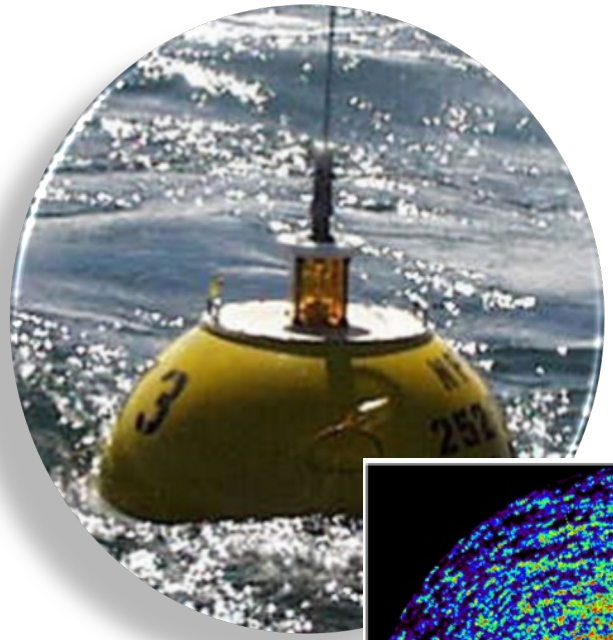
  *including wave-structure interactions aqua farming developments, mixing of water and air sea-fluxes responsible for weather and climate



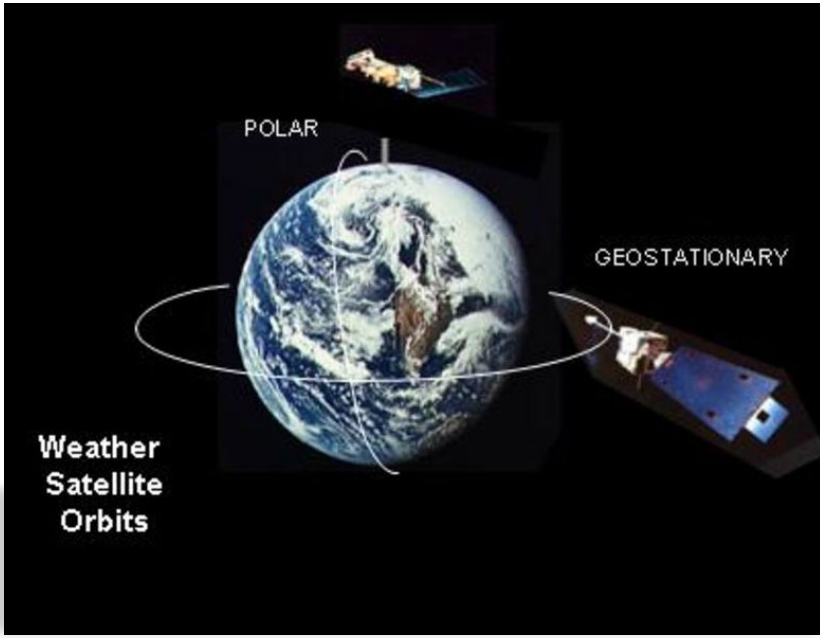
SSE from multiple observation platforms

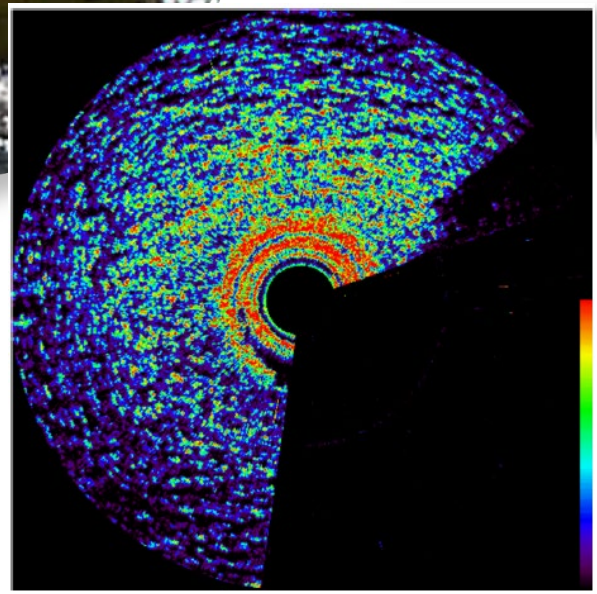
Well-known means for sea state estimation (SSE)

In-situ buoys



Remote sensing (aircraft or satellite)





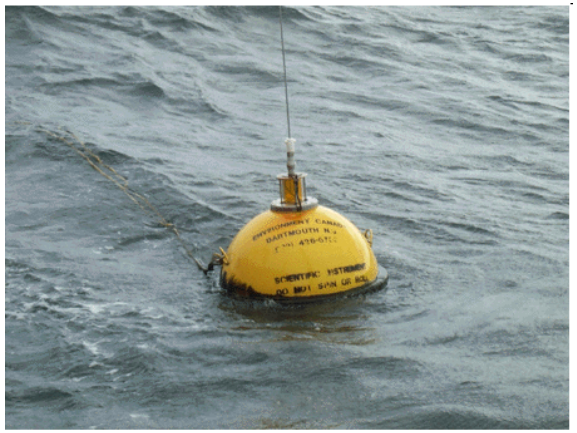
Navigational radar used as wave radar

All with their own pros and cons; <u>but</u> keep in mind we want the sea state at the *exact position* at *any moment* in time...

SSE from multiple observation platforms

An alternative means for sea state estimation

The wave buoy analogy



What is its estimation principle? It is based on measurements of the buoy's motions that are processed to give the wave spectrum (in real-time and at the buoy's exact position). We will do the same for a ship...

SSE from multiple observation platforms

"**Problems**"

- The single estimate from the individual platform is valid in a confined geographical area at current time, in fact, a bit back in time
- Associated uncertainty may be large; not to mention that it is difficult to quantify since the *ground truth* is unknown

"**Answer**":

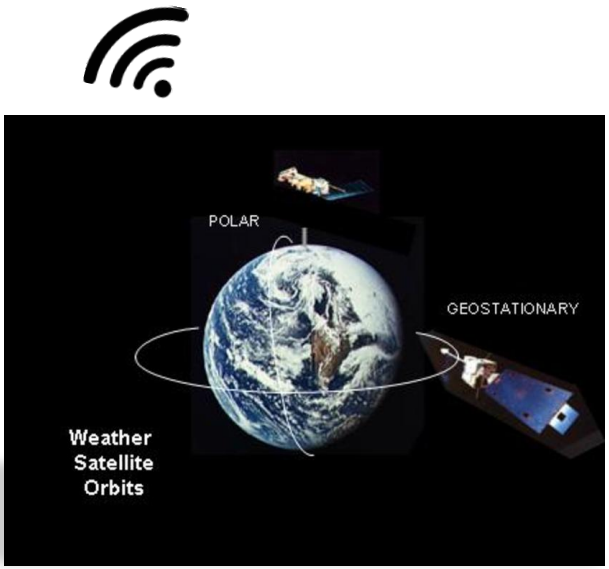
- Merge all means in a combined (heterogeneous) network of wave sensors
- Leading to improved estimates on both a local and global geographical scale, and with better *forecasted* estimates ahead of time (spatially as well as temporally)

A network of 'observation platforms'!

SSE from multiple observation platforms

Objective of this study

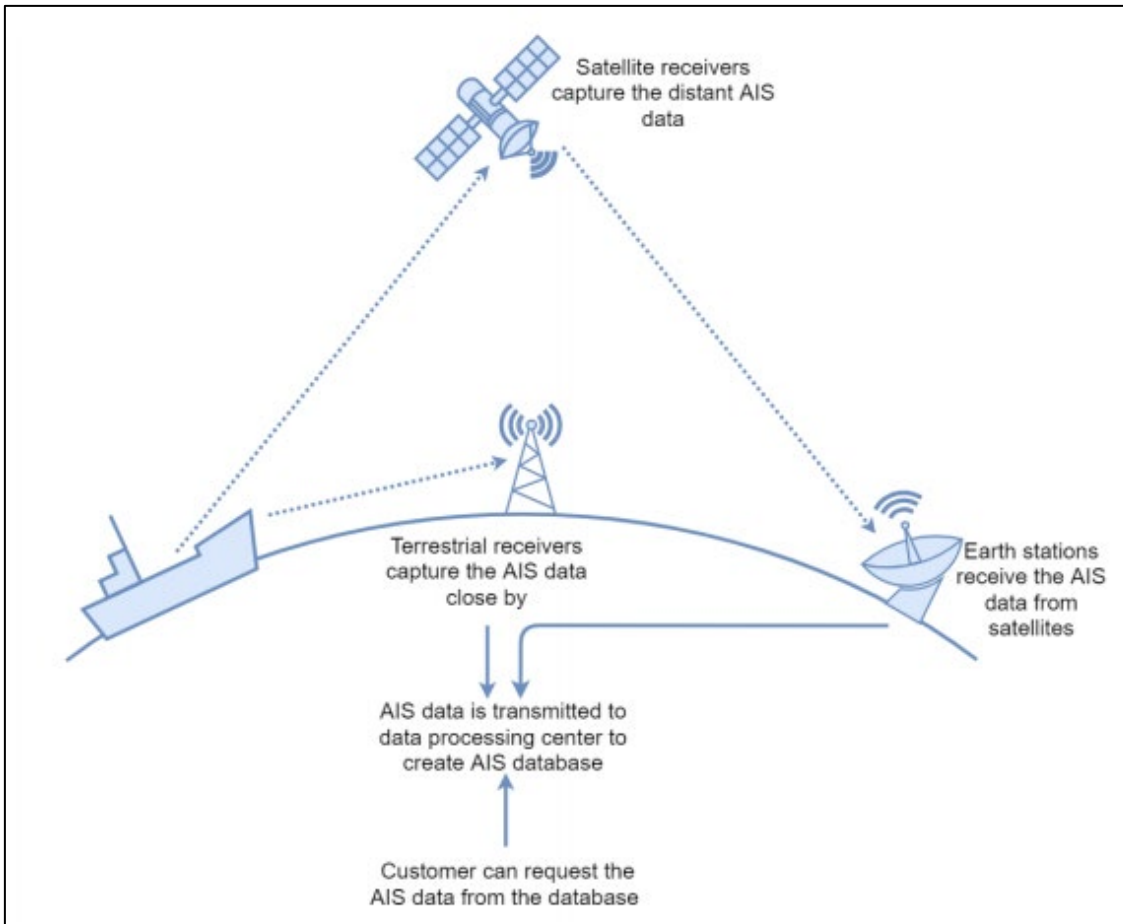
- **Introduce** the idea to apply several *platforms* simultaneously (in situ buoys, fleet of ships, remote sensing, ...) to make SSE
- This *conceptual* study "kicks off" by focusing on just one of the means (ship as a wave buoy)
- A PhD-study has be initiated in October 2020 (2020-2023).
- Results are presented by Nielsen, Brodtkorb and Sørensen (2019); limited to focus on *numerical* simulations as no experimental results exist (yet).



SSE from multiple observation platforms

Why it is *particularly* appealing to use ships as sailing wave buoys:

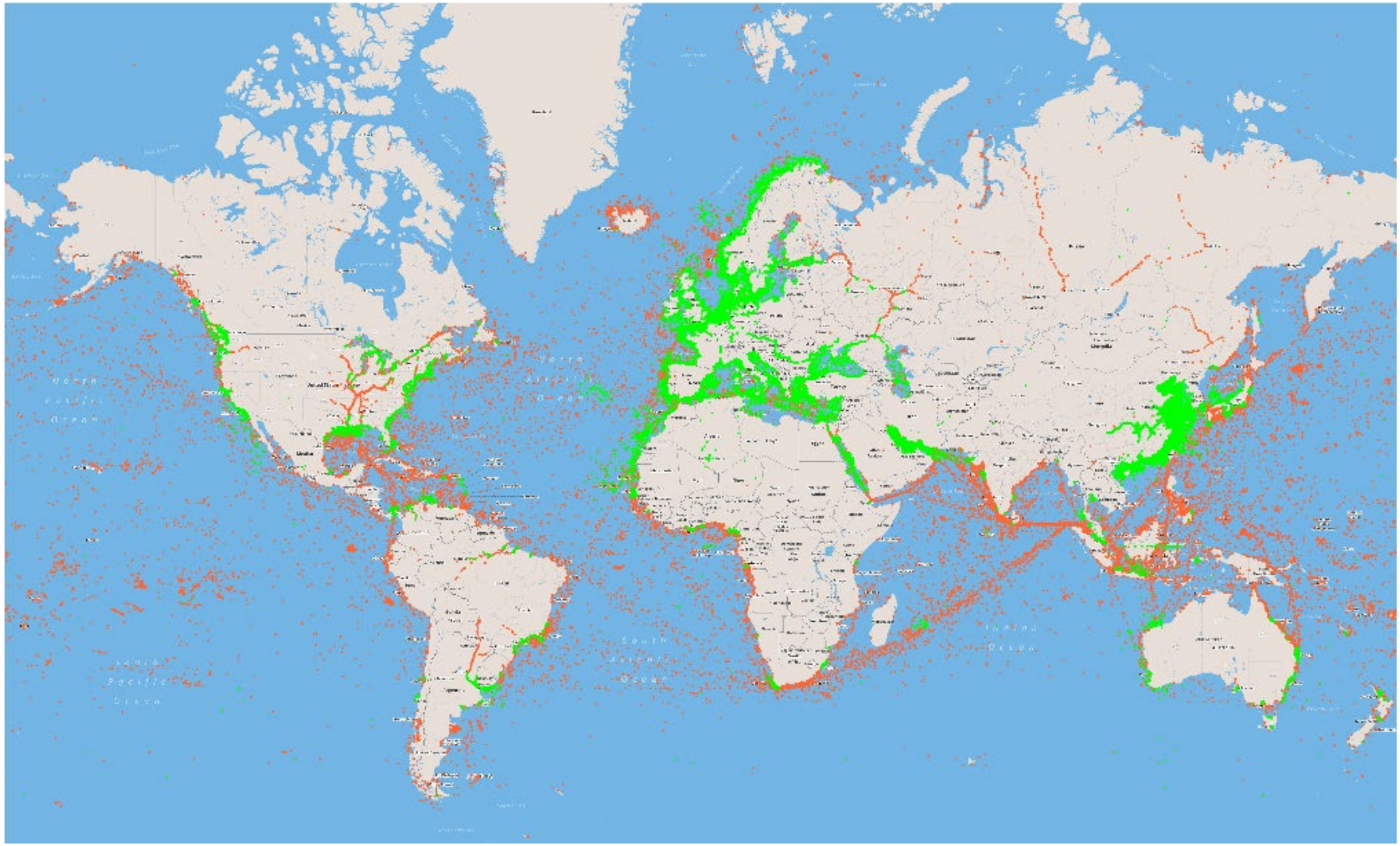
1. Sensor instrumentation is already in place on most of today's ships
2. The number of ships...



Multiple ships…

Network of ‘wave recorders’ (Nielsen et al., 2019)

Nielsen, U.D., Brodtkorb, A.H., Sørensen, A.J. (2019). Sea state estimation using multiple ships simultaneously as sailing wave buoys Applied Ocean Research, 83, pp. 65-76.



A **snapshot of vessel positions around the world’s ocean** based on data from AIS (green: terrestrial, red: satellites)

Open questions and future studies

Potential for sea state estimation using *networked and heterogeneous* sensor systems; ranging from remote sensing, fleet of ships to in situ buoys and offshore/ocean structures.

- In a network, the use of ships as wave buoys is appealing (extensive amount of data is available in real-time)! But there are many open questions:
- How should/could weighting be done, for ships?, for other platforms?
- How can estimates be forecasted, spatially and temporally? What about inclusion of effects from sea current, wind, bathymetry, ...?
- How to communicate and transfer the vast amount of data between the single platforms? (connectivity is still low at sea)?
- How could the results be linked and integrated to applications (performance monitoring, operability assessment, DSS, ...)?
- Available literature is part of the solution (de Souza, 2019; Ardhuin et *al*., 2019; Long et *al*., 2019; Mak et *al*., 2019; Nielsen et *al.,* 2019; …)

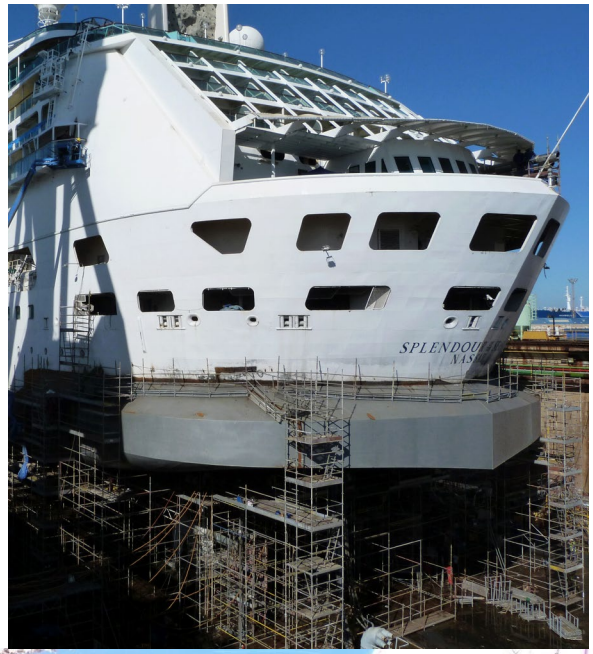
Evaluating the effect of retrofits using in-service data
(MSc study)

Evaluating the effect of retrofits

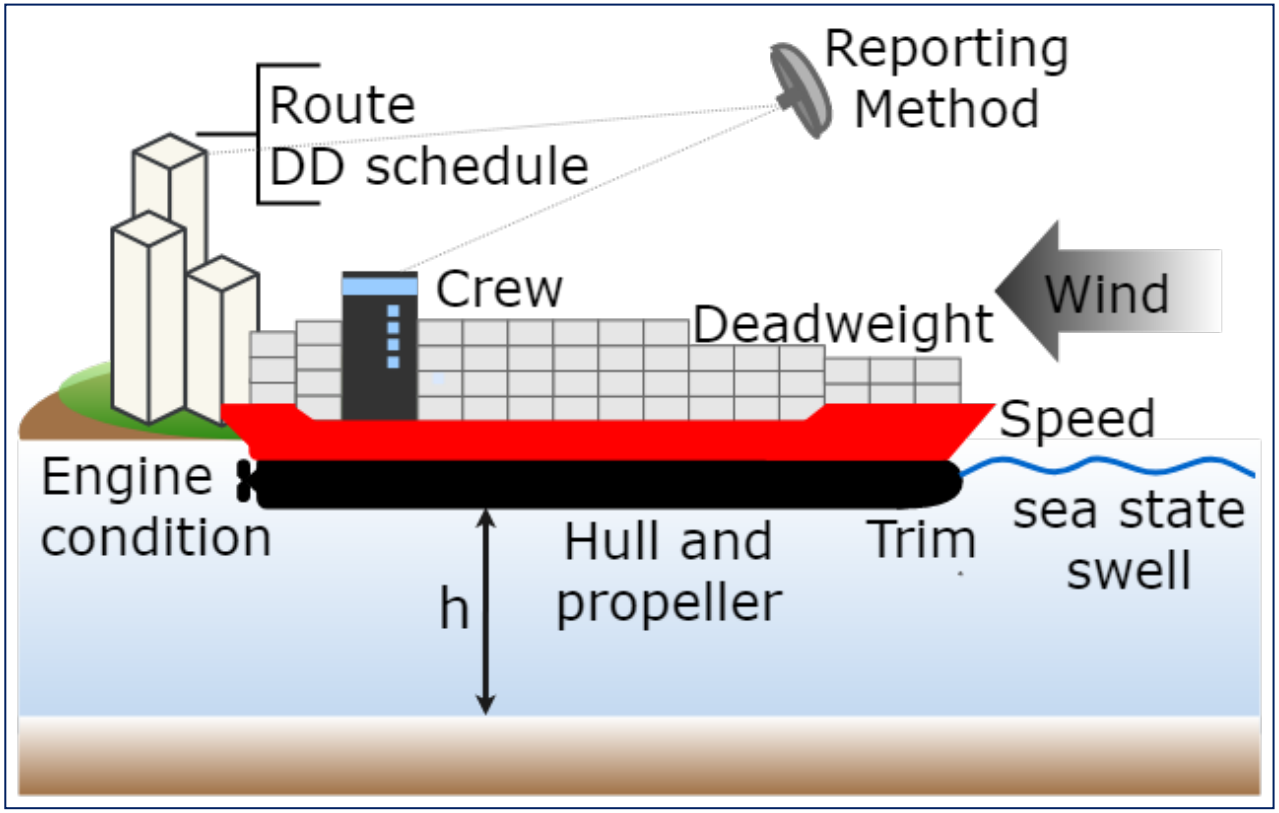
Research question: Can *in-service* data be used to evaluate the effect of retrofits while correcting for operational and environmental factors?

Motivation: RINA (2018) is calling for a framework that will make it possible to compare technologies in a fair and reliable way in order to increase the uptake of technologies that work, and speed up development of new technologies.

This project was made together with Maersk Line



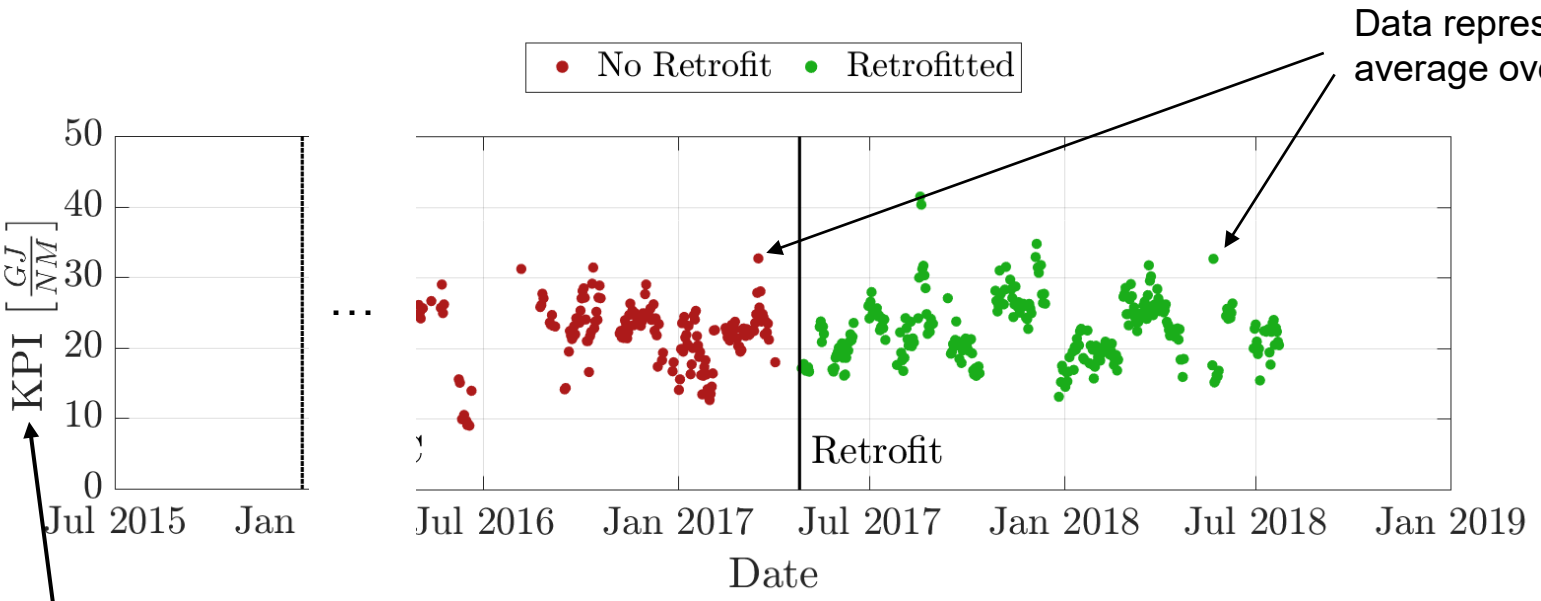
Evaluating the effect of retrofits



In-service data: *Engine (RPM, ME power, fuel flow) and loading condition (including trim), wave-induced motions, weather and wave conditions, …*

Evaluating the effect of retrofits

Does the retrofit work?



The key performance indicator (KPI) informs about *efficiency*; hence, it will be a measure of the retrofit's performance.

Evaluating the effect of retrofits

Regression Discontinuity Design (RDD)

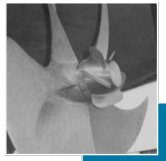
This project investigates how operational data collected on board ships can be used to evaluate the effect of a retrofit. The method ***Regression Discontinuity Design*** (RDD) is identified as a possible method for this task.

- *Econometric framework.*
- *Evaluate the causal effect of an event.*
- *Controls for other factors*

Two case studies:

Company A

- System to reduce roll.
- One container ship.
- System is turned on/off every 4 hours.
- Continuous monitoring data.

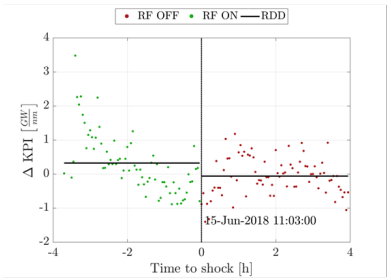


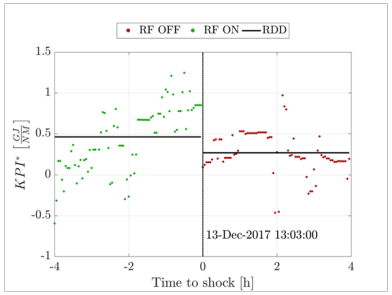
Company B

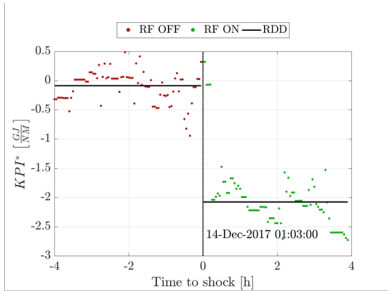
- Propeller Boss Cap Fins.
- Two bulk carriers.
- Installed during dry docking.
- Noon-report data.

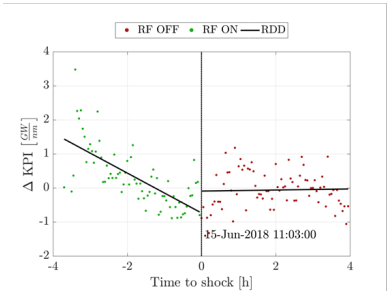
Evaluating the effect of retrofits

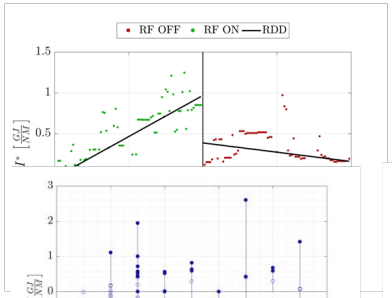
A **lot of data** was analysed based on *regression discontinuity design*…

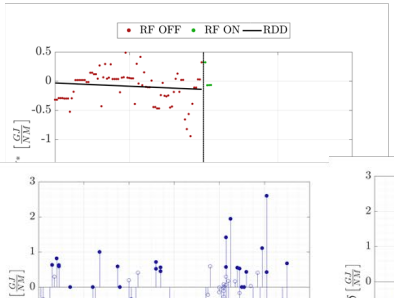


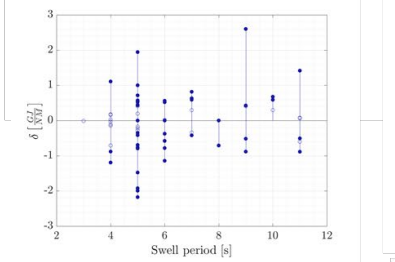


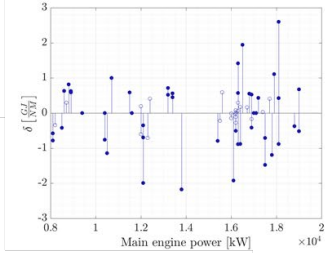


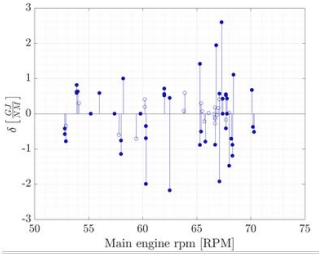


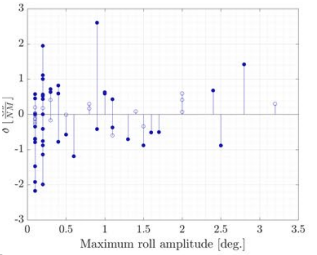


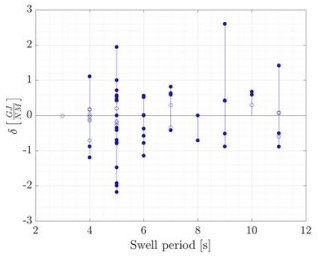


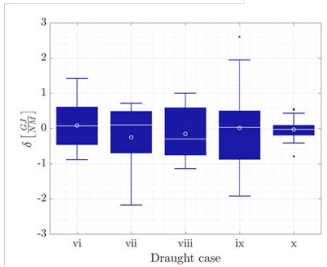


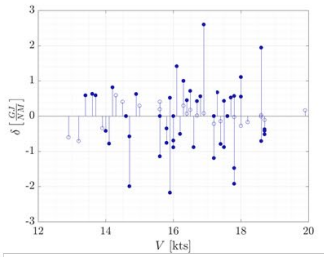


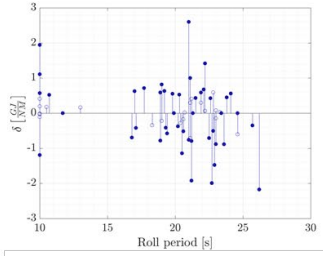












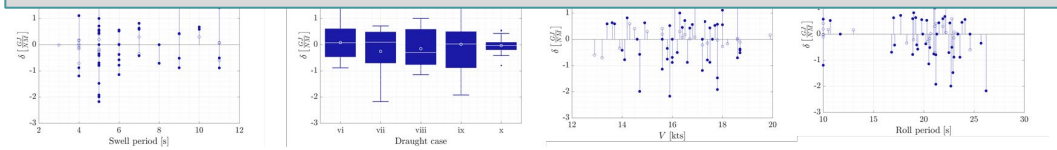
Evaluating the effect of retrofits

Two case studies

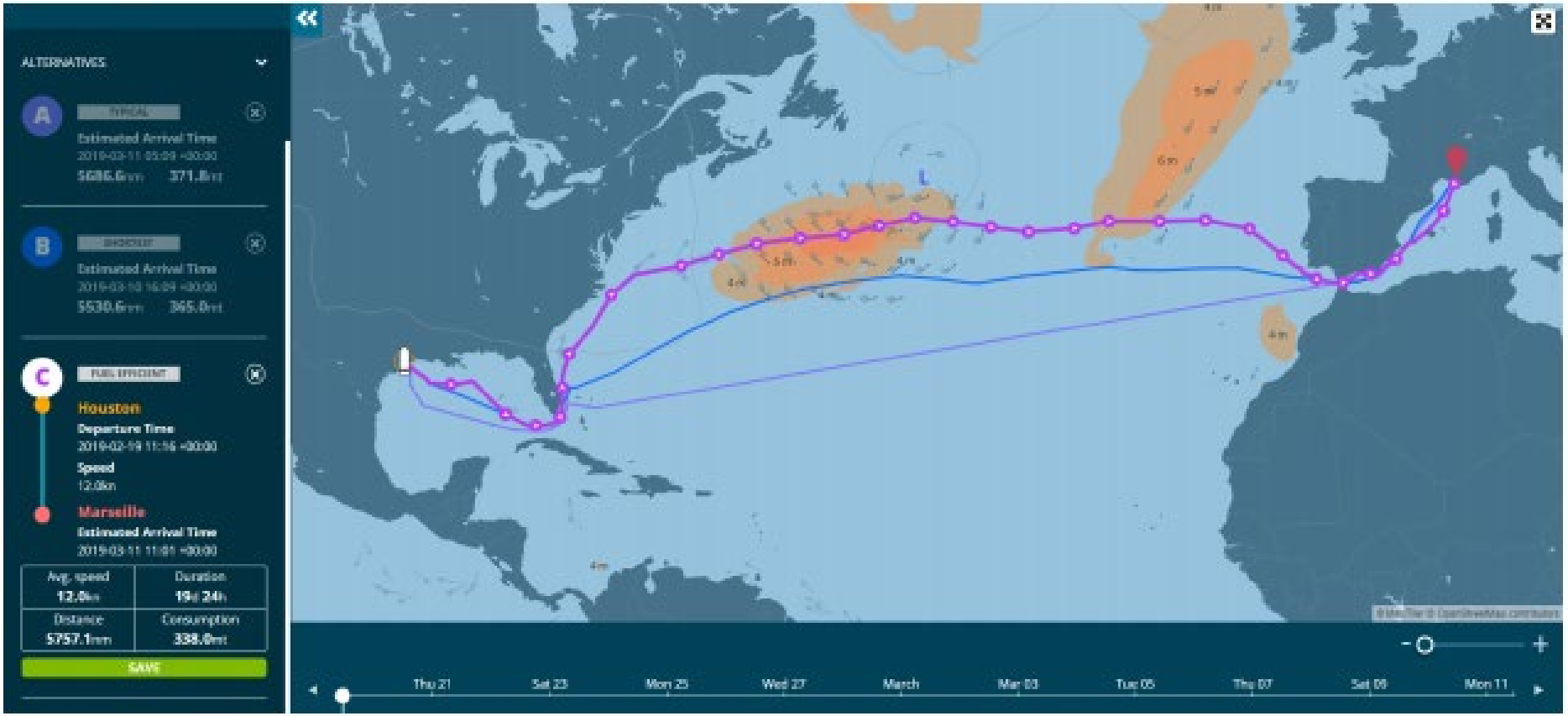
A lot of data analysis based on *regression discontinuity design*…

Conclusions and future work

- Data analysis showed little effect the retrofits; however, more importantly, the method itself, RDD, proved useful for the analysis.
- Additional methods should be tested on same data; is the analysis sensitive to the selected KPI; improved model for hull fouling is needed.



Analysis of voyage optimization benefits for different shipping stakeholders (MSc thesis)

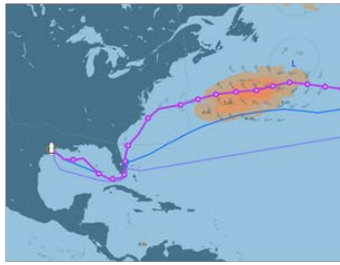


Analysis of voyage optimization benefits…

Voyage optimization processes aim to improve the operational efficiency of a ship by optimizing route and speed profiles and consequently bring economic benefit to the shipping stakeholders.

1. **What are the energy efficiency, monetary and safety benefits for voyage optimization for a fleet of specific shipowner?**

   Estimate the energy saving potential for the shipowner by running voyage simulations on realized voyages and compare the results with voyage simulations ran with different voyage optimization strategies.



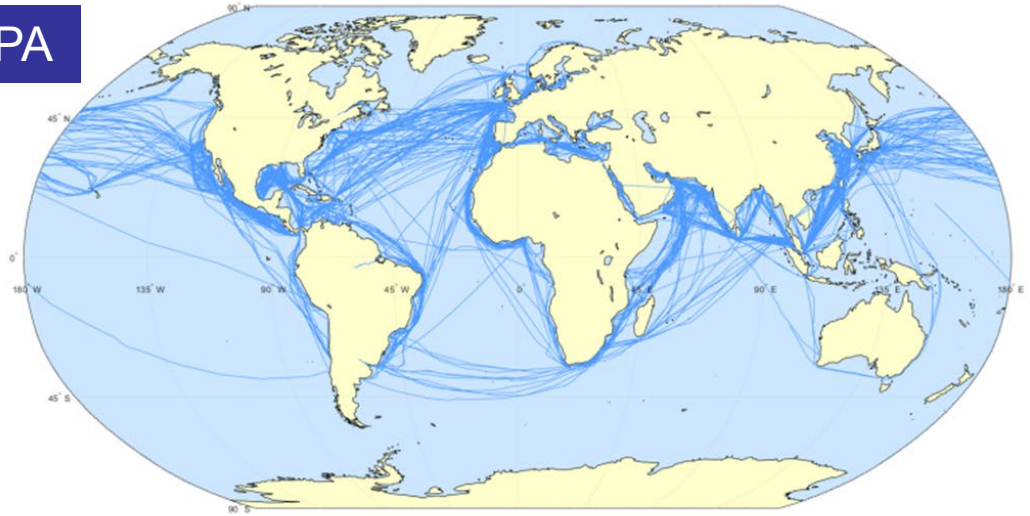
2. **How to share the monetary benefits to different shipping stakeholders, so that there is motivation to change operational processes?**

   Discuss the overall benefits from the implementation of voyage optimization processes and propose a benefit distribution scheme to share the benefits between the stakeholders.

Analysis of voyage optimization benefits…

Case study with TORM A/S and NAPA

- 49 medium range product tankers (45 000 – 55 000 DWT)
- Period under review Jan 2018 – March 2019
- Total number of voyages 1768
  - 927 laden voyages
  - 840 ballast voyages



All available AIS data of TORM ship from January 2018 to end of March 2019.

The study made a comparison between the actually made voyages (using AIS data), and corresponding simulated-optimized ones, with account to various performance metrics.

Analysis of voyage optimization benefits…

Case study with TORM A/S and NAPA

- 49 medium range product tankers (45 000 – 55 000 DWT)
- Period under review Jan 2018 – Ma
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Main findings from the study:

- Review of the benefits of voyage optimization processes
- An overview of ship performance calculations
- Simulation results by using different voyage optimization strategies
- A benefit sharing estimate by different benefit distribution schemes

The end

A number of other projects related to the use of BIG data:

- Data-driven prediction of added resistance in waves (MSc and PhD studies, 2020-2023)
- Inference of transfer functions and prediction of vessel responses using machine learning (MSc study, 2020)
- Improved accuracy of speed-through-water readings using sensor fusion (PhD study, 2019-2022)
- Short-time deterministic motion prediction using process correlation structures (PostDoc study, 2019-2020)
- A design tool for early evaluation of compliance with minimum propulsion power requirements (2019-2020)
- A decision support tool based on virtual structural hull monitoring (2020)
- Investigation of vessel performance benchmarking at speed intervals below the design speed (2021)
- …

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