Photo: North Sea, A. Rialland, 2020

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SHIP MODEL-BASED ROUTE OPTIMISATION FOR DECISION SUPPORT IN DEEP SEA SHIPPING

Yauheni KISIALIOU, Agathe RIALLAND (presenter), Victoria GRIBKOVSKAIA

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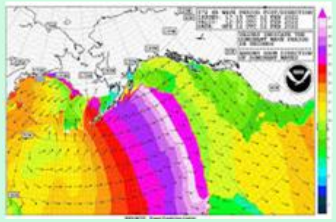
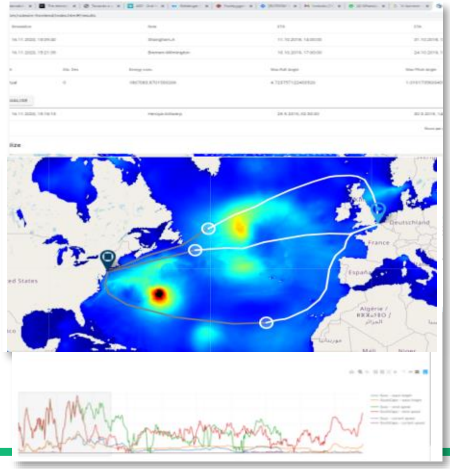
Combining ship modelling, route optimization and weather data

Combining ship modelling, route optimization and weather data to enable ship routing minimizing power consumption & voyage duration

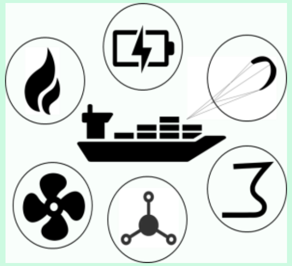
WEATHER DATA



REAL SEA CONDITIONS



TECHNOLOGY SELECTION



VESSEL MODEL

OPTIMIZATION ALGORITHM

SHIP ROUTING

SHIP MODEL-BASED ROUTE OPTIMISATION FOR DECISION SUPPORT IN DEEP SEA SHIPPING

- Route optimization methodology to support analysis and planning of vessel performance in deep sea shipping for green, energy efficient, and safe navigation.
- Methodology combines:
  - the ship technical characteristics based on a ship model developed for a particular vessel type and energy-saving technology options
  - an optimization algorithm taking into account weather conditions.
- Optimization involves two stages:
  - graph construction
  - Dynamic Programming labelling algorithm implemented to solve the shortest path problem with variable speed.
- The approach is implemented as part of a decision-support tool EcoRouter enabling the user to conduct analysis of safe and Pareto optimal solutions.
- Several applications to support fleet planning and ship performance analysis

Application areas

Estimate potential of novel technology / retrofit considering optimal operational profile

Novel Technology Selection for own fleet

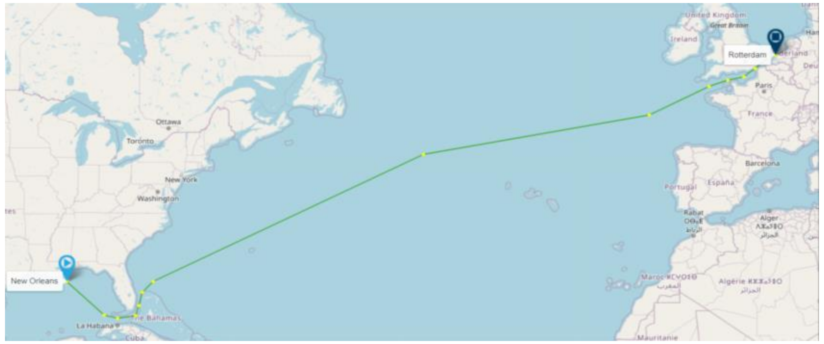
Input to voyage planning and optimization

THE ROUTE OPTIMIZATION MODEL

Ship-model based route optimization solution approach

- Bi-objective resource-constrained shortest path problem with variable speed and weather conditions.
- Two objectives – time and power consumption - implies that the solution to the problem is represented by a set of Pareto optimal solutions

Input



- **Reference route** (rtz, WPlist, manual)
- **Departure time options**. to find a more favorable weather window resulting in a more energy efficient and safe solution.
- **ETA slot**: earliest and latest possible
- **Weather data**: wind, wave and sea currents. This can be either historical data or forecast:
  - Wind speed
  - Wind direction
  - Wave direction
  - Wave height
  - Wave period
  - Current direction
  - Current speed
- **Vessel characteristics**: numerical model for a specific vessel estimating the vessel power consumption in given sea state, speed, heading.
- **Safety limitations**. Safety thresholds are defined by critical values of weather conditions' estimates when it is either prohibited to sail or some action such as speed change is required
- **Speed allowed**: min-max (knot), intervals, speed variation

Model used for demo cases

- Based on the SINTEF Ocean Bulk Carrier SOBC-1
- Generic medium-size, medium range, single-screw tank/bulk carrier, but having unconventional main dimensions
  - Lpp 190m
  - B 32.2 m
  - H 23.5 m
  - Operation speed range 8-15 knots
  - Installed power 8500 KW
- More info: https://github.com/SINTEF/sobc-1-benchmark-data/blob/main/SO_Benchmark_Bulk_Carrier_SOBC-1_VKr_ICN-Meeting-030522.pdf


Photo: SINTEF Ocean

Model used in route optimization = a pre-processed **interpolation model / lookup-table** :

- Lightning fast
- Little loss in fidelity

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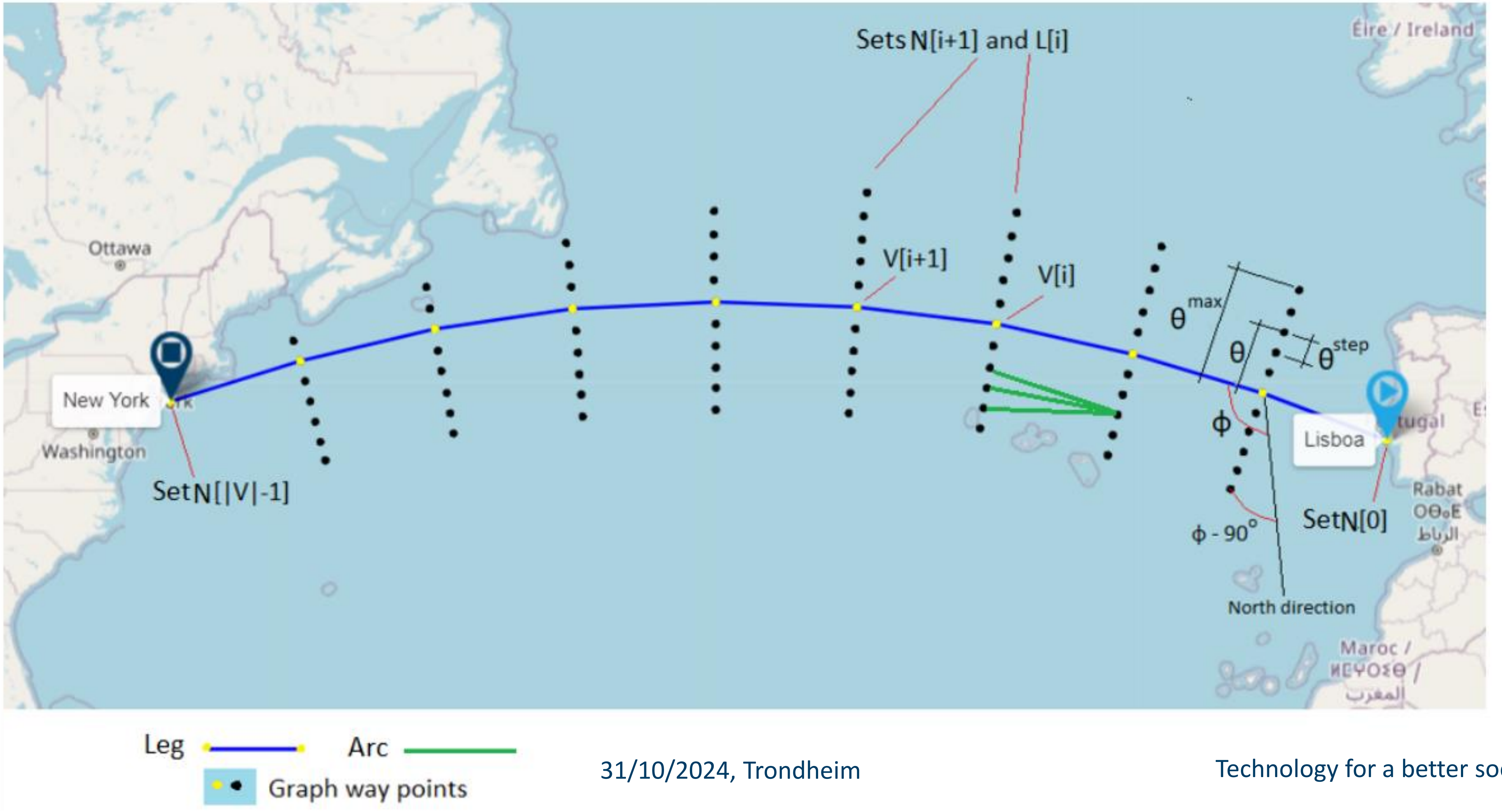
OPTIMIZATION

- Shortest path with resource constraint: time and power consumption
- Graph construction: constructs a graph covering a certain corridor around the reference route
- Dynamic Programming labelling: the algorithm recursively explores potential sailing options for all nodes. Decisions variables considered:
  - Sailing direction. The options are defined by the graph arcs.
  - Speed selection along a voyage leg (graph arc). The speed between any two nodes is assumed to be constant.
  - Departure time

Graph construction parameters



Power calculation

- The vessel’s power required to maintain a certain speed is a function f p (Ω(t, i), u, λ) of the speed u, heading λ, weather estimates Ω(m, i) at particular time interval number m and location i.
- Calculation function performs interpolation of the power value for the actual inputs based on the input ship-file values. The energy c computation, required to cover a certain distance l with a certain speed s is defined as power f p multiplied by the sailing time t.
- Safety considerations: Combinations of wave height (Hs) and wind speed (Ws) defines the condition for sailing along the leg.

Weather data

- The weather data is provided for the geographical region defined by the graph extreme coordinates and the time span between the earliest departure and latest arrival time.
- For any fractional time of t hours after departure, the respective time interval number m is calculated as $m = \lfloor t/\delta \rceil$ i.e the respective nearest. The weather conditions are assumed to be constant within the interval δ and the vessel's speed along an arc is constant.

APPLICATION CASES

Application cases

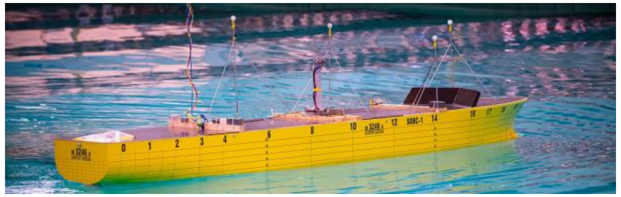
- Case 1: Impact of new technology

explore the potential benefits of ship technical improvements (here wind-assisted propulsion – retrofit)

- Case 2: Voyage optimization

energy saving potential of voyage optimization, flexible scheduling and speed range, considering the impacts of weather and ship characteristics

The **vessel data file (test file)** used as input for the route optimization, has been pre-generated based on the reference ship SOBC-1. Contains all data points of the vessel's power estimates required to maintain a certain speed at a certain direction under different weather conditions.



Weather data used in route optimization for both cases was retrieved from the Copernicus Data Space Ecosystem providing open and free access Earth observation data.

Case 1: Impact of new technology

- Objective: Route optimisation for conventional vessel vs. wind-assisted
- Test voyage: Cape of Good Hope to Sao Paolo – Eastbound, Westbound
- Route optimization speed range: 12 to 14 knots
- Vessel files: based on SOBC-1 Conventional and SOBC-1 Wind-assisted
- Test schedule: January, April, July, October 2023 – departure 1st of each month

Optimization result (january)

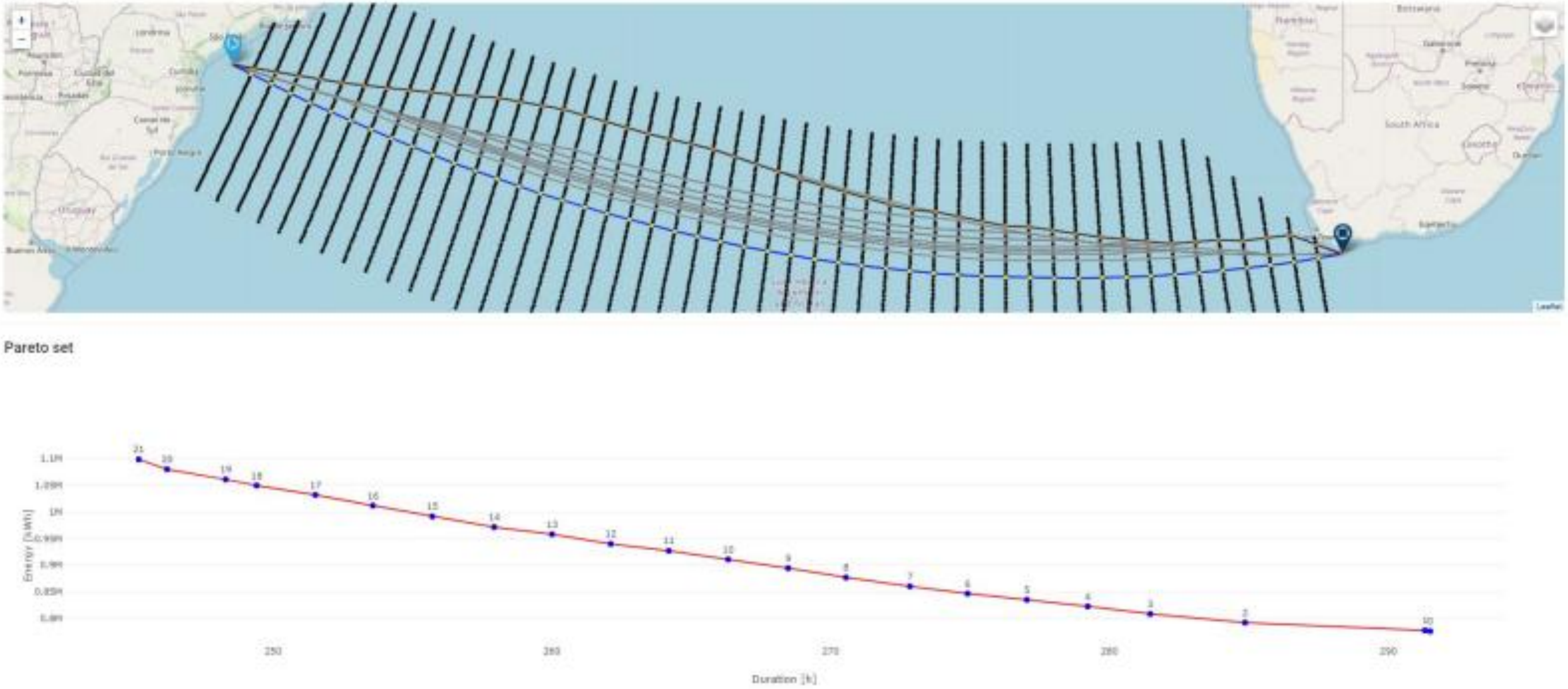
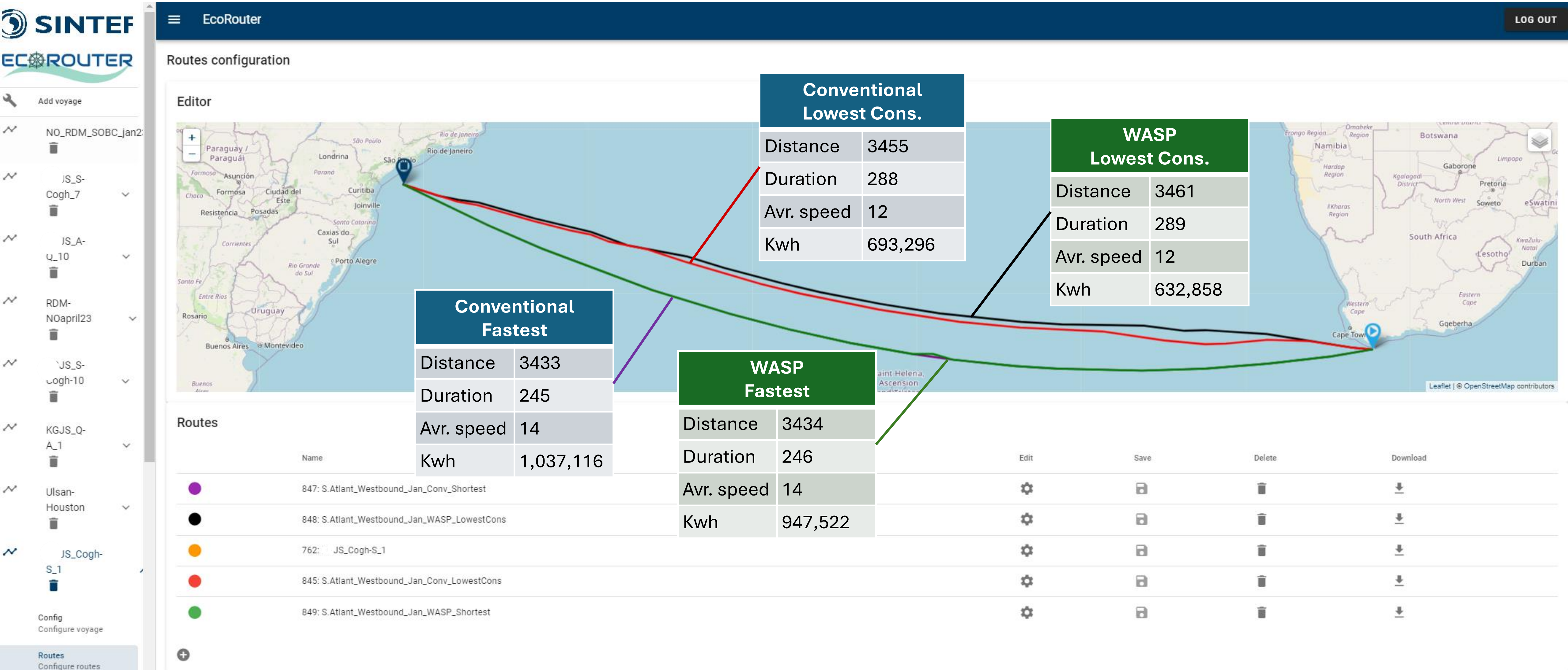


Figure 2: Route optimization results for the eastbound South Atlantic voyage with the conventional ship, January 2023

Fastest and Lowest consumptions routes

Case January (ETD 01/01/2024)



Conventional Lowest Cons.

Distance	3455
Duration	288
Avr. speed	12
Kwh	693,296

WASP Lowest Cons.

Distance	3461
Duration	289
Avr. speed	12
Kwh	632,858

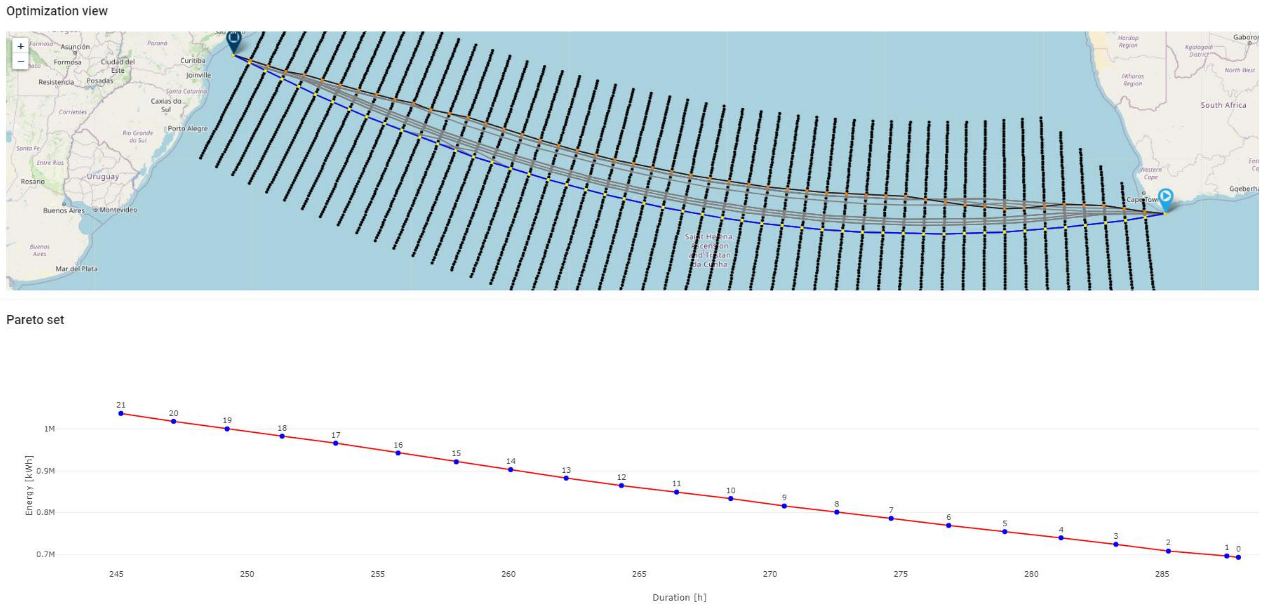
Conventional Fastest

Distance	3433
Duration	245
Avr. speed	14
Kwh	1,037,116

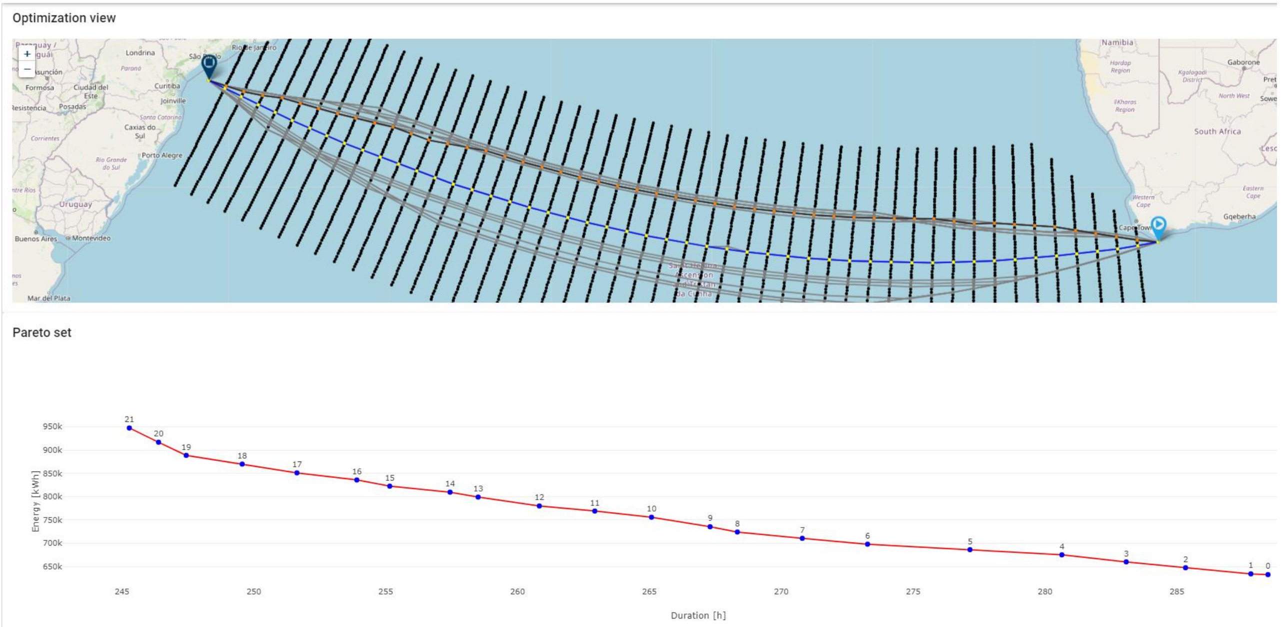
WASP Fastest

Distance	3434
Duration	246
Avr. speed	14
Kwh	947,522

Conventional



Wind-assisted



Juxtaposition of Pareto sets

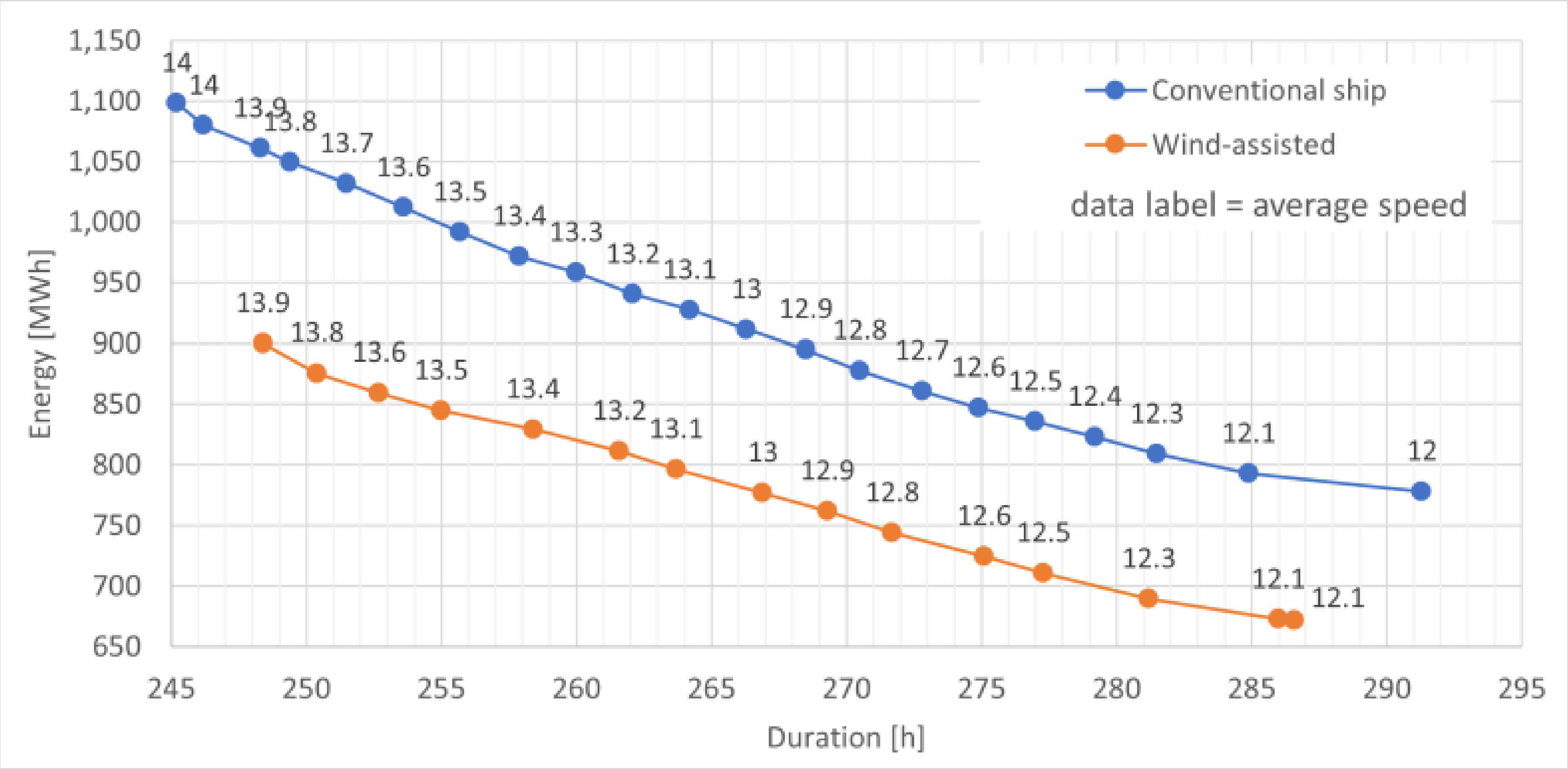


Figure 3: Pareto-optimal routes of each ship model for the South Atlantic voyage, January 2023.

Summary of optimization results

Summary of route optimization results

W/E: west/Eastbound

1-4: january, April, july, October

C/F: lowest consumption / fastest route

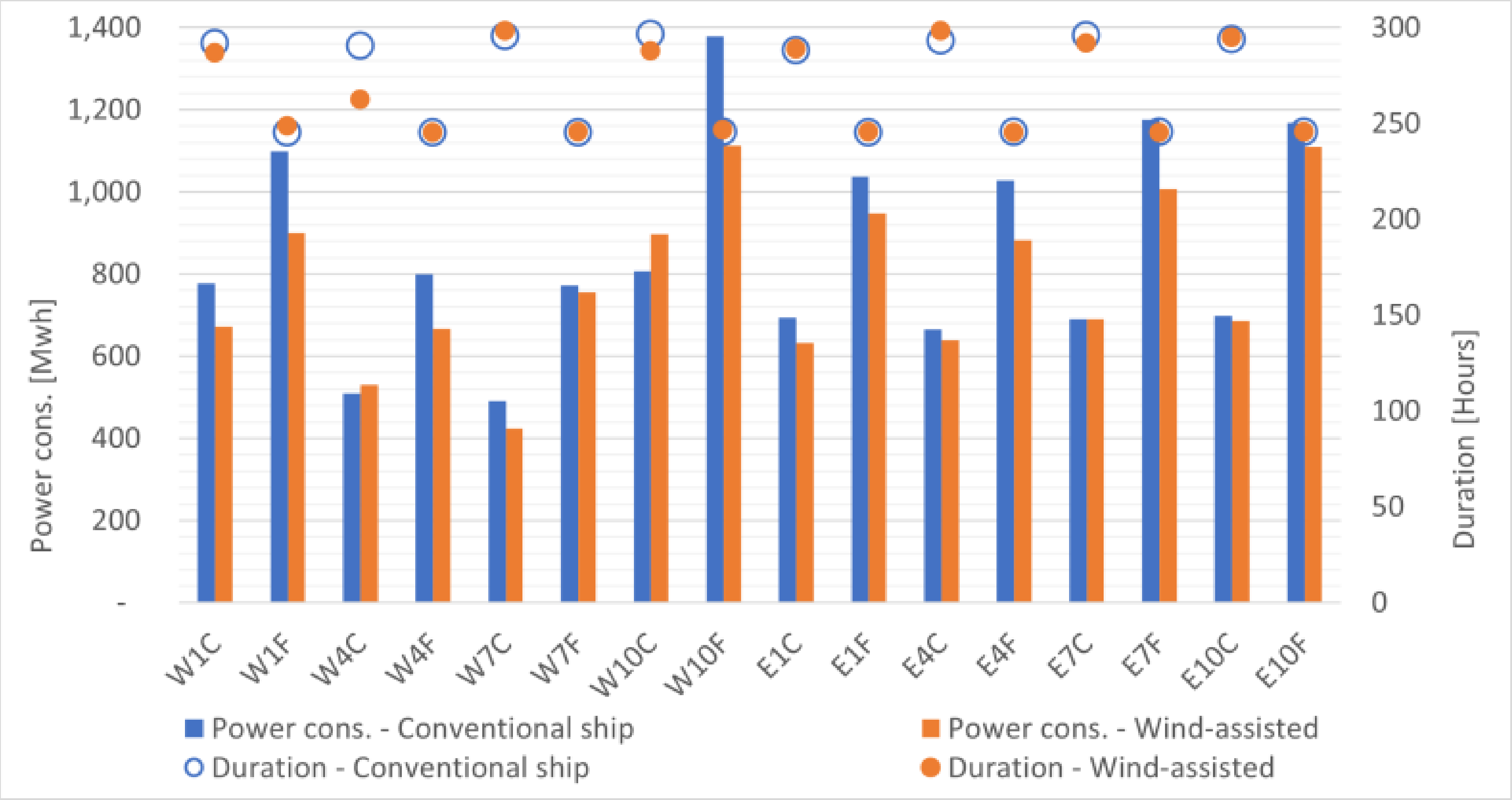


Figure 4: Summary of main results from each route optimization scenario with each ship models

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Case 2: Voyage optimization

- Objective: study of optimal routes depending on various operational strategies such as a wider speed range (allowing the ship to deviate from the speed agreement) or of more flexible scheduling (identifying optimal routes based on flexible departure and open arrival time).
- Voyage: Rotterdam – New Orleans
- Speed range for optimization: either fixed at any integer value between 10 to 15 knots or flexible between 10 and 15 knots
- Vessel files: based on SOBC-1 Conventional
- Schedule: departure on April 1st 2023

Optimization result (january)

- Blue line: fastest
- Black line: lowest consumption
- Departure options (+0,12,24h)
- No fixed required arrival time

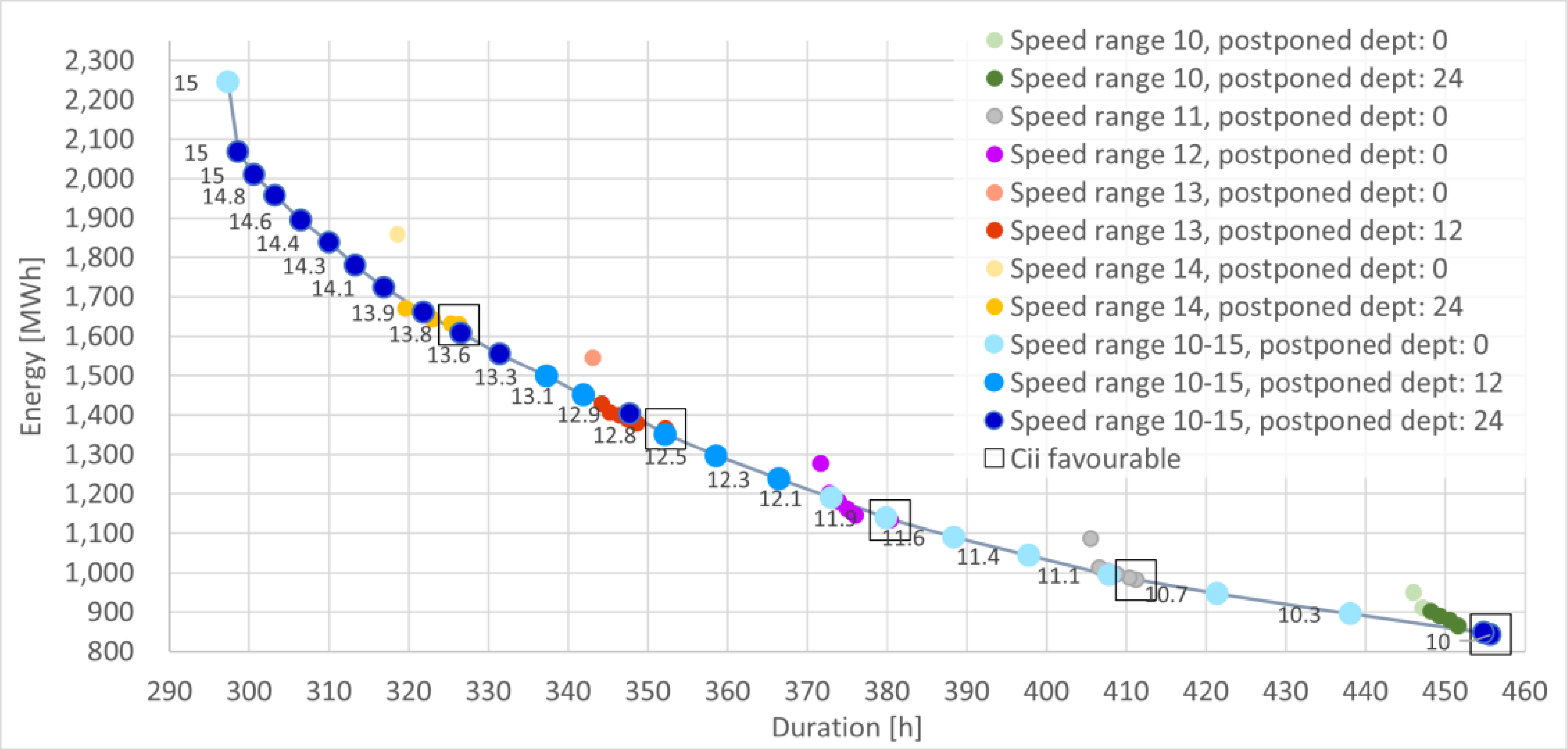

Figure 6: Pareto optimal route characteristics for the North Atlantic voyage scenario considering both fixed and variable speed constraints

Conclusion

- The ship model-based route optimization enables the study of optimal routes and vessel performance considering specific ship characteristics from a particular ship model and real sea and weather conditions.
- A set of time- and energy- optimal routes, varying in path, speed during voyage and departure schedule, can be identified for a specific vessel and energy saving technology for given weather conditions.
- Further work:
  - Functional adjustment for use in study of potential of route optimization.
  - Further development of optimization parameters, constraints and settings for operational applications (weather uncertainty; multiple vessels; navigational constraints)

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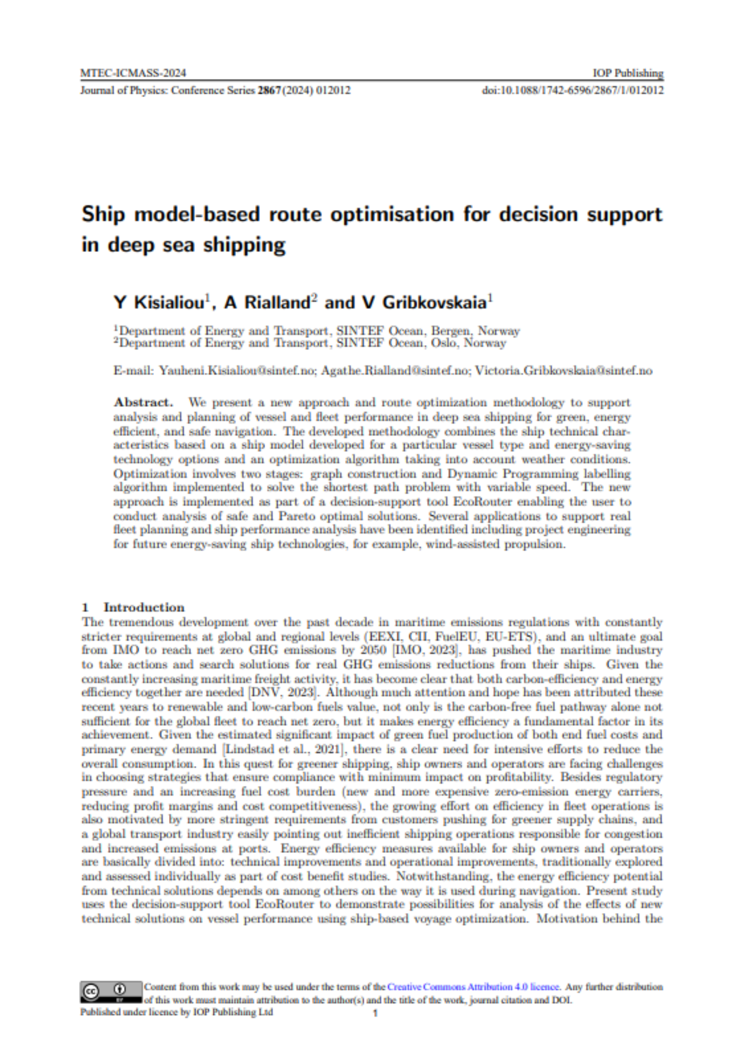
Thank you for your attention

Yauheni Kisialiou

Agathe Rialland

Victoria Gribkovskaia



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Ship model-based route optimisation for decision support in deep sea shipping

Y Kisialiou[1], A Rialland[2] and V Gribkovskaia[1]

[1]Department of Energy and Transport, SINTEF Ocean, Bergen, Norway
[2]Department of Energy and Transport, SINTEF Ocean, Oslo, Norway

E-mail: Yauheni.Kisialiou@sintef.no; Agathe.Rialland@sintef.no; Victoria.Gribkovskaia@sintef.no

Abstract. We present a new approach and route optimization methodology to support analysis and planning of vessel and fleet performance in deep sea shipping for green, energy efficient, and safe navigation. The developed methodology combines the ship technical characteristics based on a ship model developed for a particular vessel type and energy-saving technology options and an optimization algorithm taking into account weather conditions. Optimization involves two stages: graph construction and Dynamic Programming labelling algorithm implemented to solve the shortest path problem with variable speed. The new approach is implemented as part of a decision-support tool EcoRouter enabling the user to conduct analysis of safe and Pareto optimal solutions. Several applications to support real fleet planning and ship performance analysis have been identified including project engineering for future energy-saving ship technologies, for example, wind-assisted propulsion.

1 Introduction

The tremendous development over the past decade in maritime emissions regulations with constantly stricter requirements at global and regional levels (EEXI, CII, FuelEU, EU-ETS), and an ultimate goal from IMO to reach net zero GHG emissions by 2050 [IMO, 2023], has pushed the maritime industry to take actions and search solutions for real GHG emissions reductions from their ships. Given the constantly increasing maritime freight activity, it has become clear that both carbon-efficiency and energy efficiency together are needed [DNV, 2023]. Although much attention and hope has been attributed these recent years to renewable and low-carbon fuels value, not only is the carbon-free fuel pathway alone not sufficient for the global fleet to reach net zero, but it makes energy efficiency a fundamental factor in its achievement. Given the estimated significant impact of green fuel production of both end fuel costs and primary energy demand [Lindstad et al., 2021], there is a clear need for intensive efforts to reduce the overall consumption. In this quest for greener shipping, ship owners and operators are facing challenges in choosing strategies that ensure compliance with minimum impact on profitability. Besides regulatory pressure and an increasing fuel cost burden (new and more expensive zero-emission energy carriers, reducing profit margins and cost competitiveness), the growing effort on efficiency in fleet operations is also motivated by more stringent requirements from customers pushing for greener supply chains, and a global transport industry easily pointing out inefficient shipping operations responsible for congestion and increased emissions at ports. Energy efficiency measures available for ship owners and operators are basically divided into: technical improvements and operational improvements, traditionally explored and assessed individually as part of cost benefit studies. Notwithstanding, the energy efficiency potential from technical solutions depends on among others on the way it is used during navigation. Present study uses the decision-support tool EcoRouter to demonstrate possibilities for analysis of the effects of new technical solutions on vessel performance using ship-based voyage optimization. Motivation behind the

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