SPECIAL-PURPOSE WEATHER ROUTING: AUTONOMOUS AND WIND-DRIVEN SHIPS

COMPIT 2015

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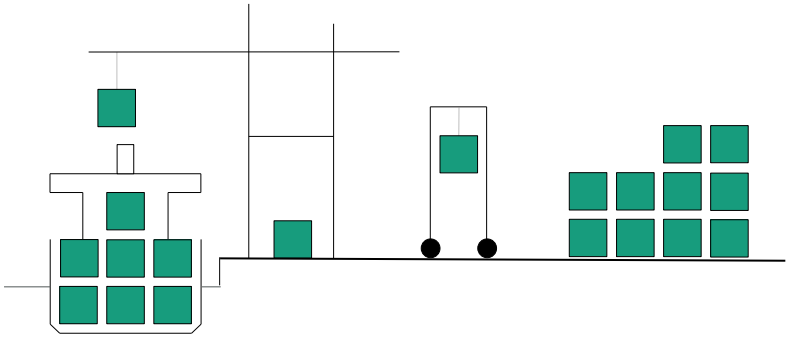

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Motivation

- Ship design process generally driven by three pillars
  - Safety of human life
  - Protection of the environment
  - Economic feasibility

- Development of innovative ship concepts
  - Autonomous ships, such as DNV-GL's ReVolt, by Rolls-Royce or MUNIN
  - Wind-driven ships, such as Vindskip™

→ Need for optimisation not only in design but also operation

AGENDA

1. Motivation
2. **Fundamentals**
3. Requirements of innovative ship concepts
4. Generic weather routing framework
5. Test scenarios
6. Conclusions

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Fundamentals of safe, ecologic and efficient operation

- Safe operation
  - Three quarters of all losses in 2013 due to foundering with bad weather as significant driver *(Safety and Shipping Review 2014)*
- Ecologic operation
  - Airborne emissions are regulated in MARPOL Annex VI
  - Different fuel oils used by many ships to comply with limits in ECAs
- Economic operation
  - Mandatory measures concerning fuel efficiency by IMO
  - Energy Efficiency Design Index (EEDI)

General weather routing requirements

- Optimising each voyage requires
  - Variation of heading → Route optimisation
  - Variation of speed → Speed optimisation

- Quality of the optimised route strongly depends on
  - Weather forecast quality
  - Optimisation method
  - Consideration of ship specific data

→ Innovative and complex ships necessitate accurate consideration of ship specific characteristics by customised solution to optimise safe, ecologic and economic operation

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1. Motivation
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3. **Requirements of innovative ship concepts**
    1. Autonomous ships
    2. Wind-driven ships
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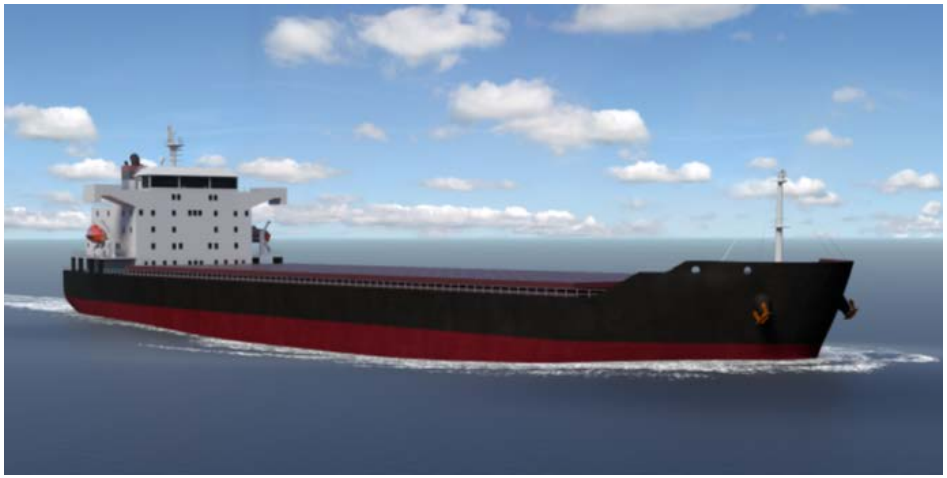
The MUNIN project

- Autonomous and unmanned dry bulk carrier (L=225m, B=32.26m)
- Intercontinental deep-sea voyage
- Autonomous navigation system follows voyage plan, makes decisions within operational envelope supported by real-time sensor data
- Monitoring and intervention possibilities by shore control centre



MUNIN

European Commission

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Requirements of autonomous ships

- Objective
  - Operate at least as safe as manned vessel

- Requirements regarding weather routing
  - Logging, monitoring and intervention possibilities by a shore control centre
  - On-board version executable and autonomously operating without satellite communication link
  - Combination of weather routing with collision avoidance
  - Integration of strategic weather routing and operational routing
  - Consideration of advanced sensor data

The Vindskip™ project

- Developed by Terje Lade, Lade AS
- Wind-driven hybrid merchant vessel with innovative hull shaped like symmetrical air foil (L=200m, B=49m)
- Relative wind generates aerodynamic lift pulling ship forward
- Additionally equipped with LNG electric propulsion system

LadeAs

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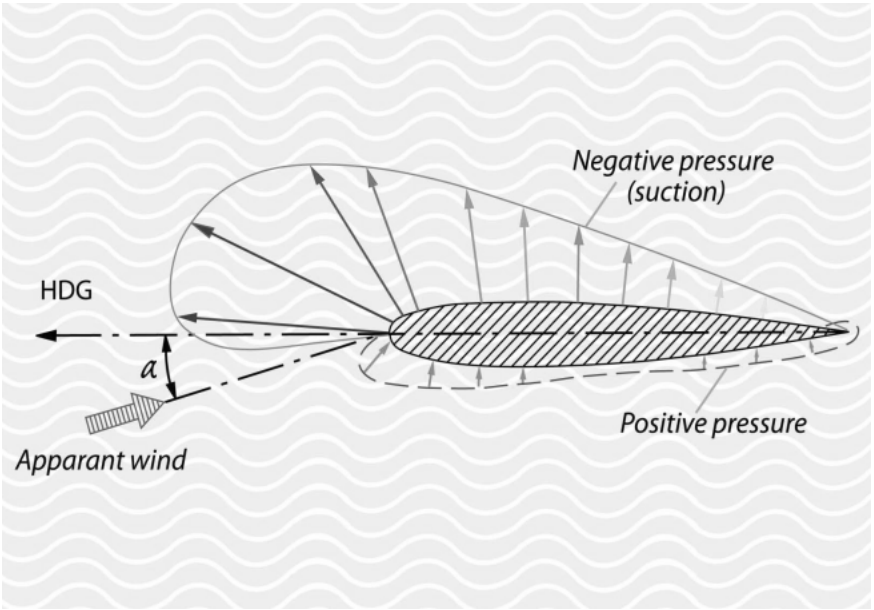
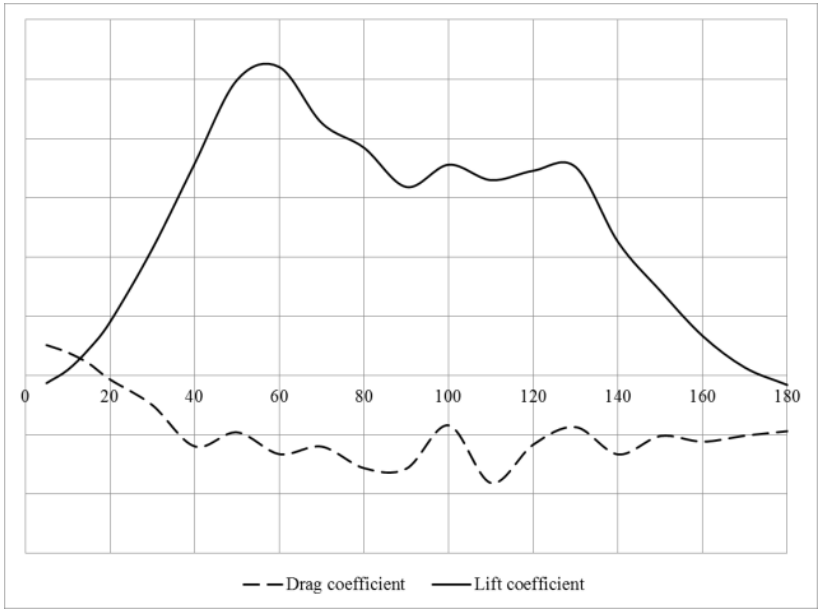
The Vindskip™ concept

Pressure distribution air foil



Drag and lift coefficient



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Requirements of wind-driven ships

- Objective
  - Utilise available wind energy as efficiently as possible

- Requirements regarding weather routing
  - Accurate consideration of wind forecasts and resulting apparent wind
  - Customised calculation methods for wind resistance based on aerodynamic data
  - Enhanced calculation methods to derive hydrodynamic forces and moments

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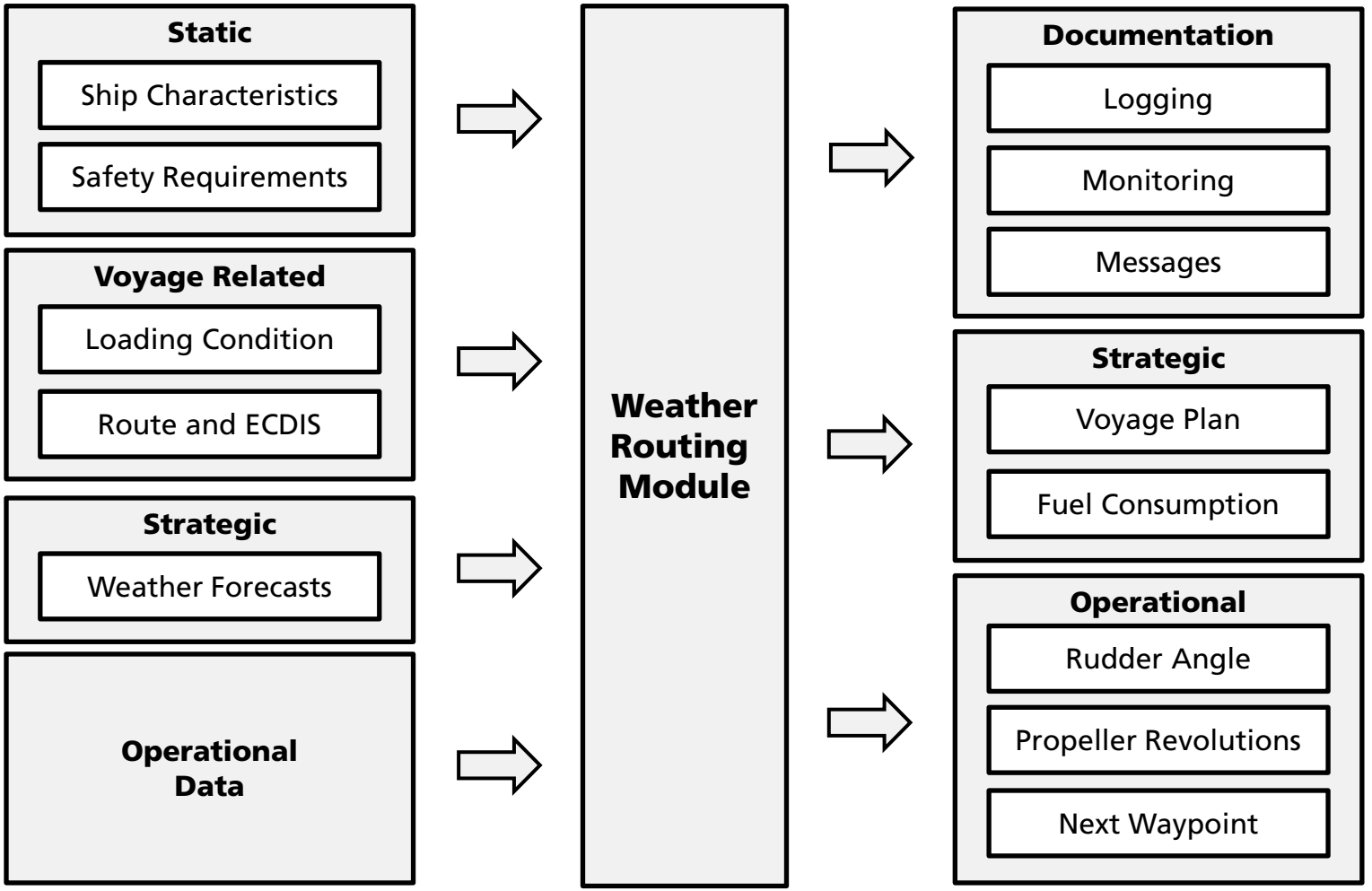
Generic weather routing framework



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Algorithm
Weather routing problem

- Problem
  - Finding route with the lowest fuel consumption considering weather forecasts and avoiding obstacles

- Approach
  - Variations of Dijkstra's algorithm generally deployed
  - Special purpose weather routing modules use A* algorithm
  - Optimisation based on 2D grid defined by GRIB data
  - Extension in temporal domain to allow optimisation of ship's speed
  - Consideration of route, safety and operational restrictions

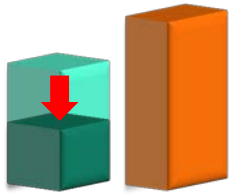
Algorithm

Target function and variables

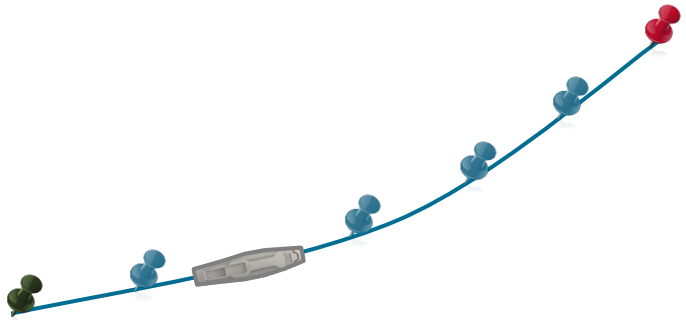
- Target function

  $F(k) = G(k) + H(k) \leq min\{G(i) + H(i) \mid i \in B\}$

  - Minimise fuel-consumption, and thus costs per voyage
  - Combines exact costs $G(k)$ of path from start to any vertex k with heuristic estimated cost $H(k)$ from this vertex to destination



- Variables
  - Position of waypoint φ_k, λ_k [°,°]
  - Time at waypoint t_k [h]



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    2. Vindskip™
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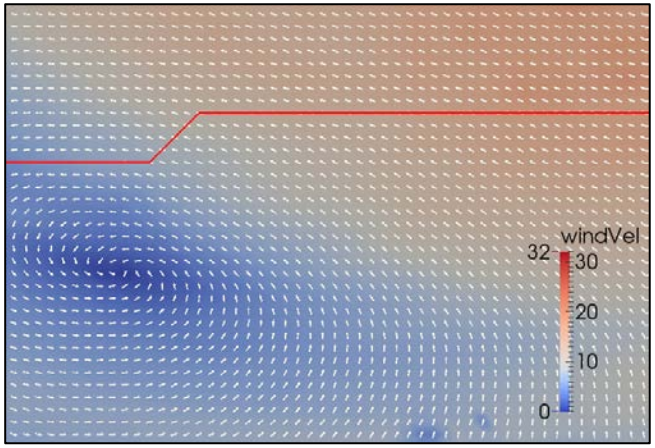
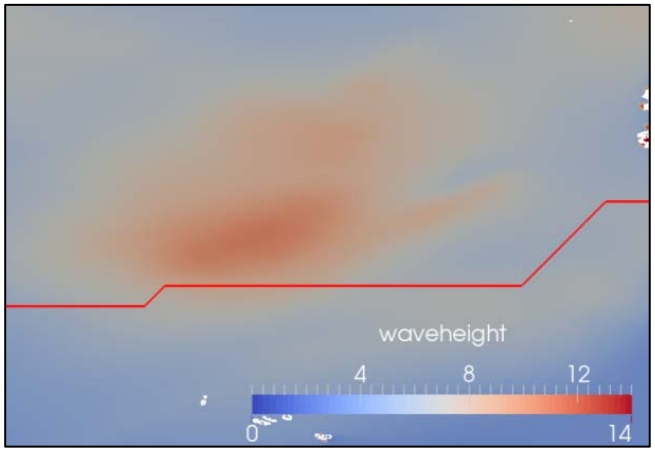
MUNIN's strategic routing test

Transatlantic route

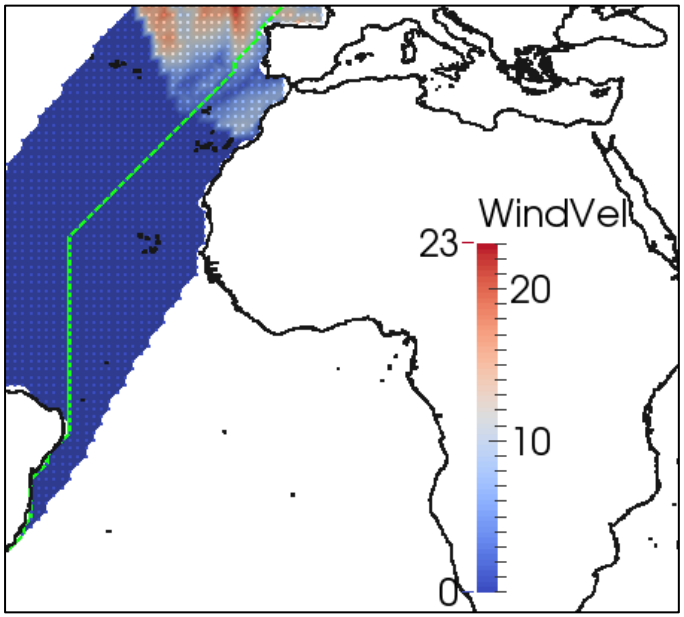
Wind speed test



Wave height test



Routing test



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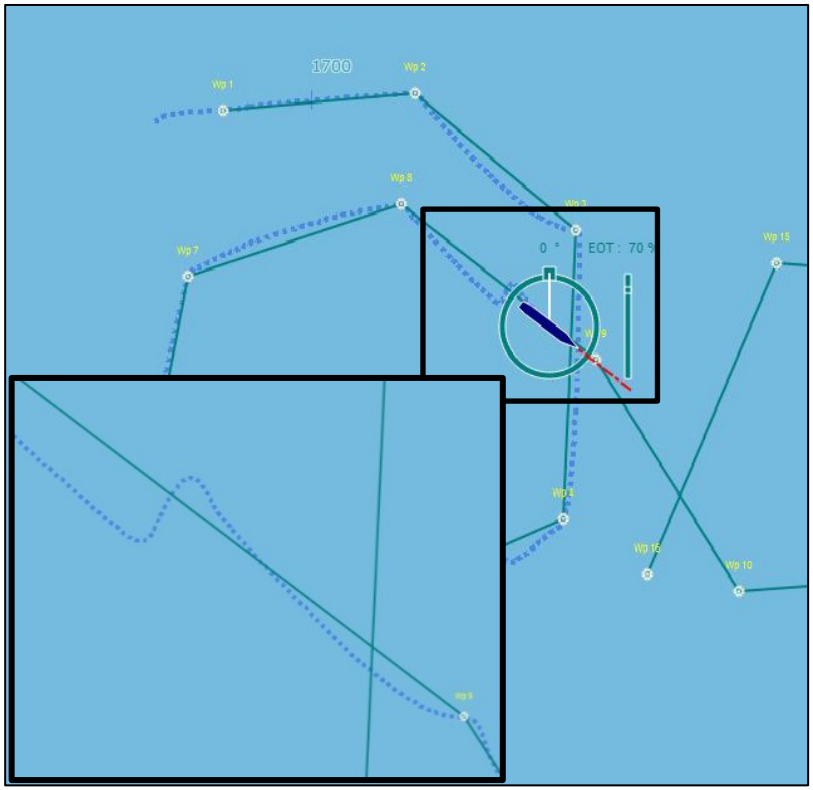
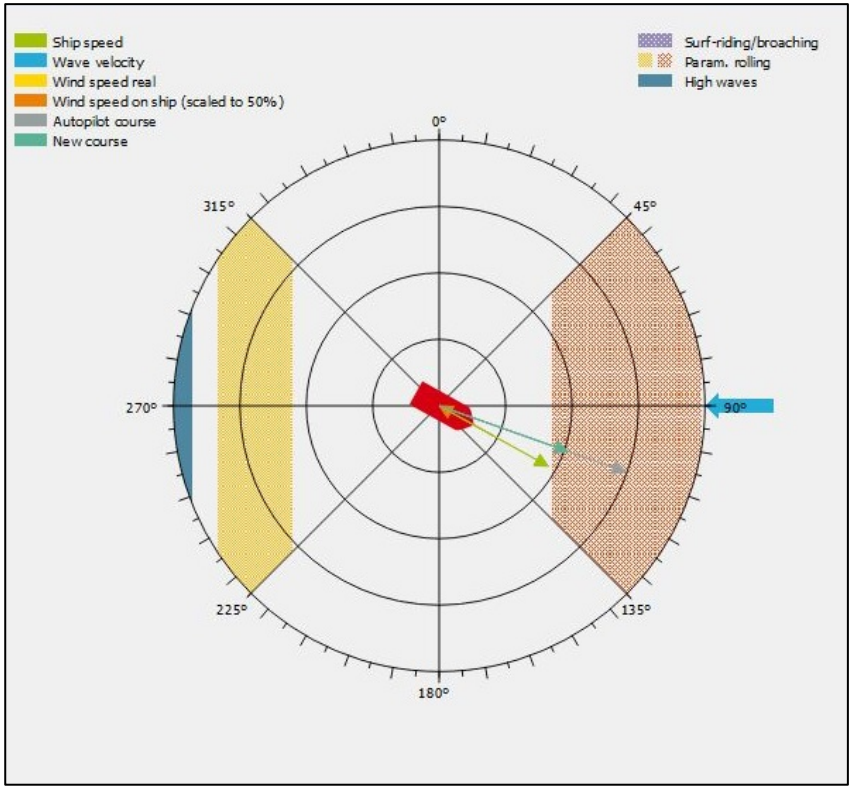
MUNIN's operational routing test

Ship's behaviour almost in head waves and sea state 8

Ship's route



Polar plot



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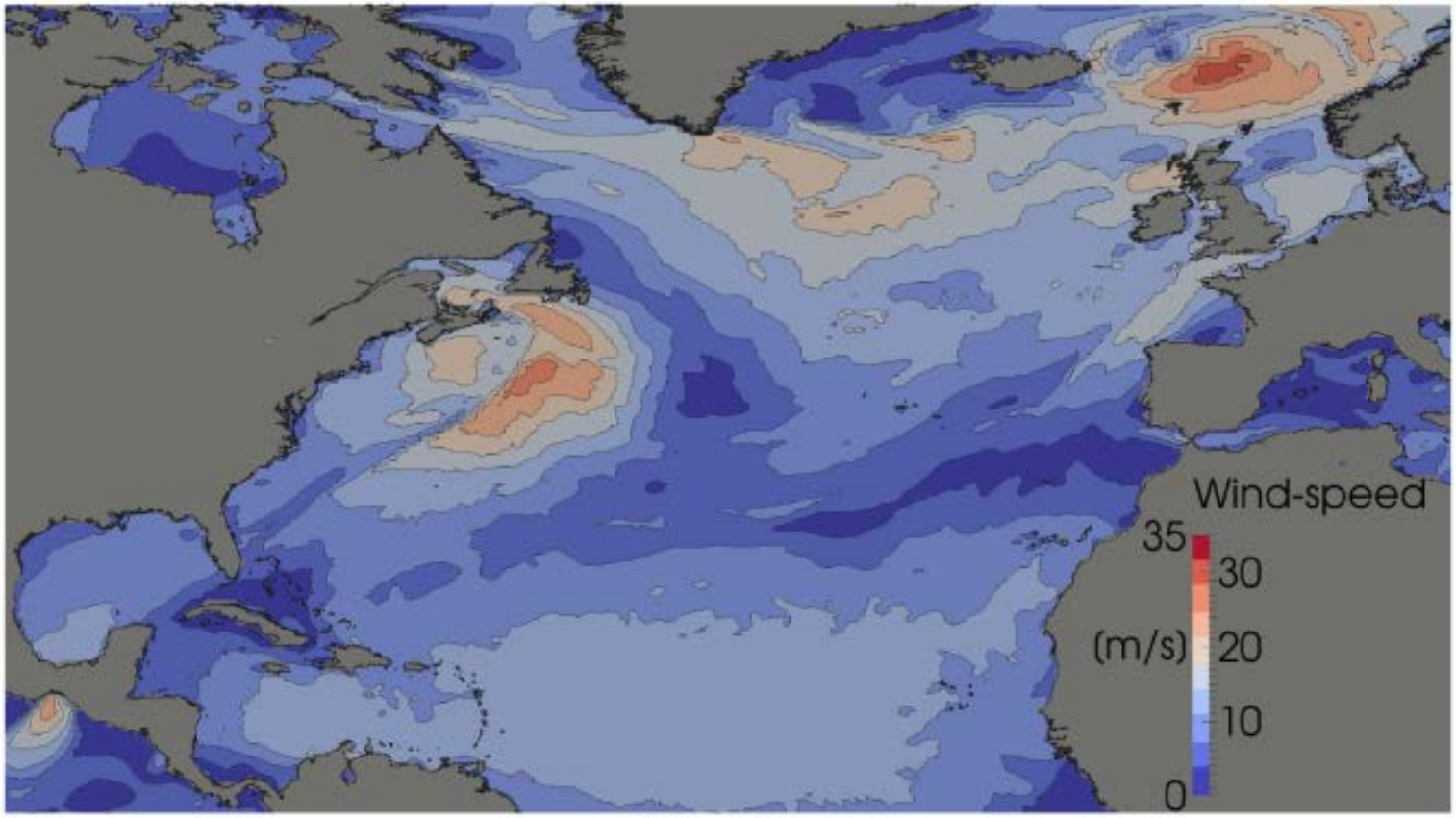
Vindskip™'s routing test

Wind speed forecast on 2013/12/16



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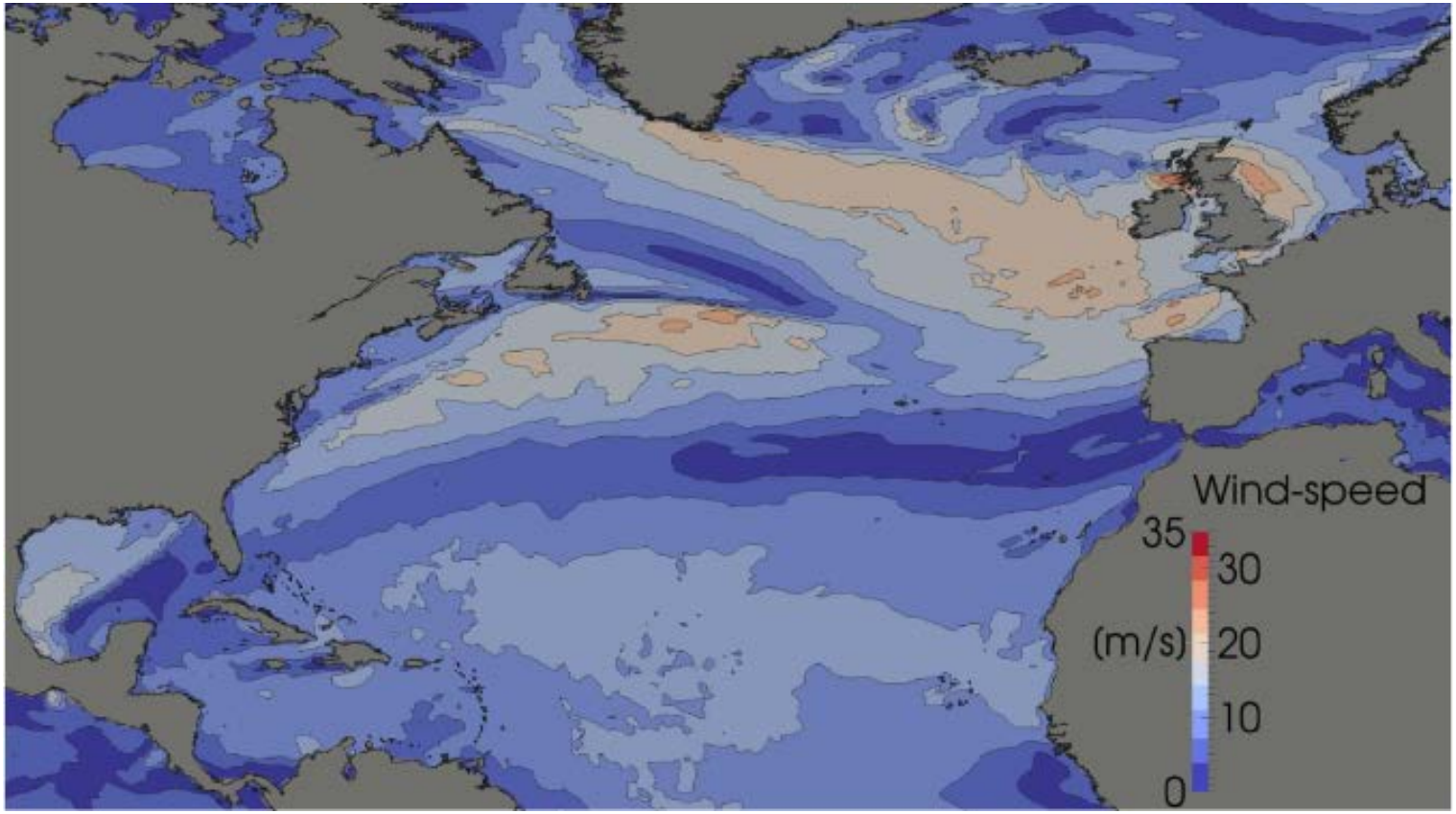
Vindskip^{TM}'s routing test

Wind speed forecast on 2013/12/23



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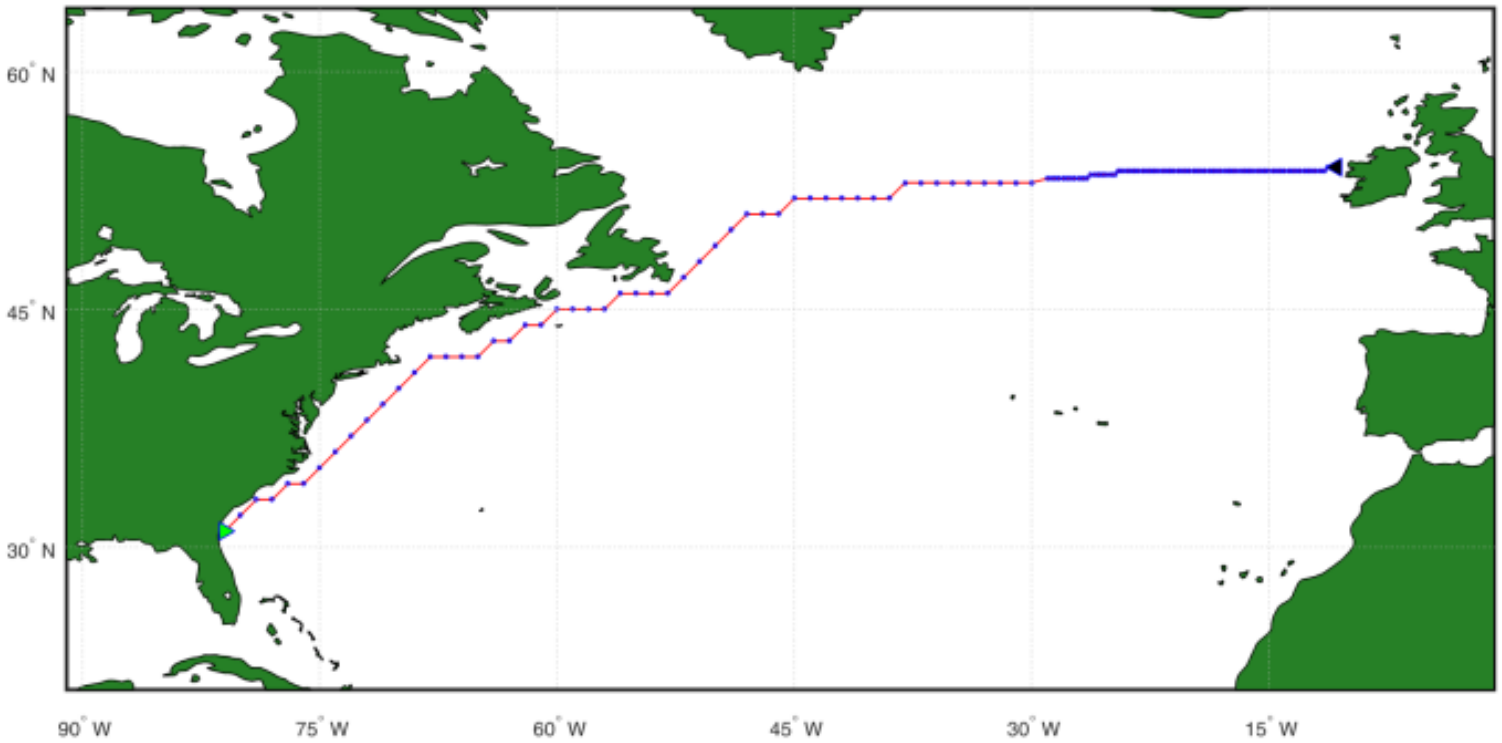
Vindskip™'s routing test

Route from Ireland to Florida



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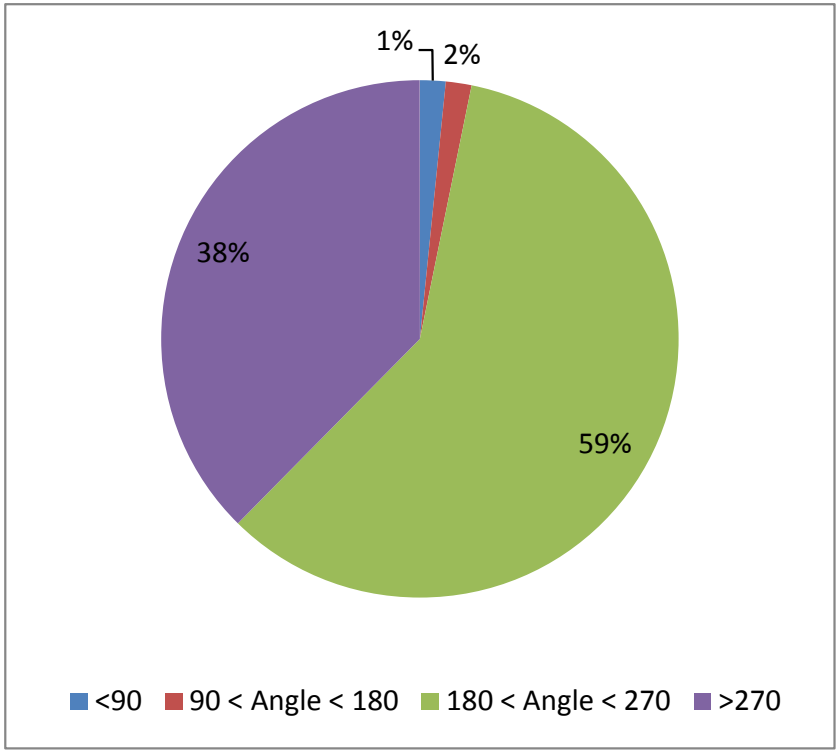
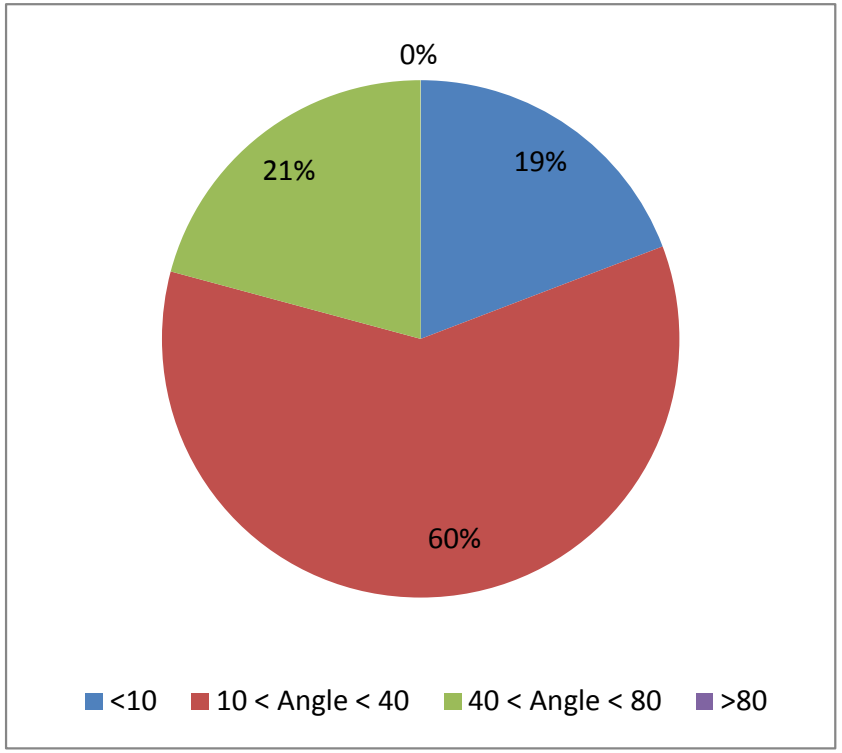
Vindskip™'s routing test

Wind assessment on route from Ireland to Florida

True wind direction



Angle of attack of apparent wind



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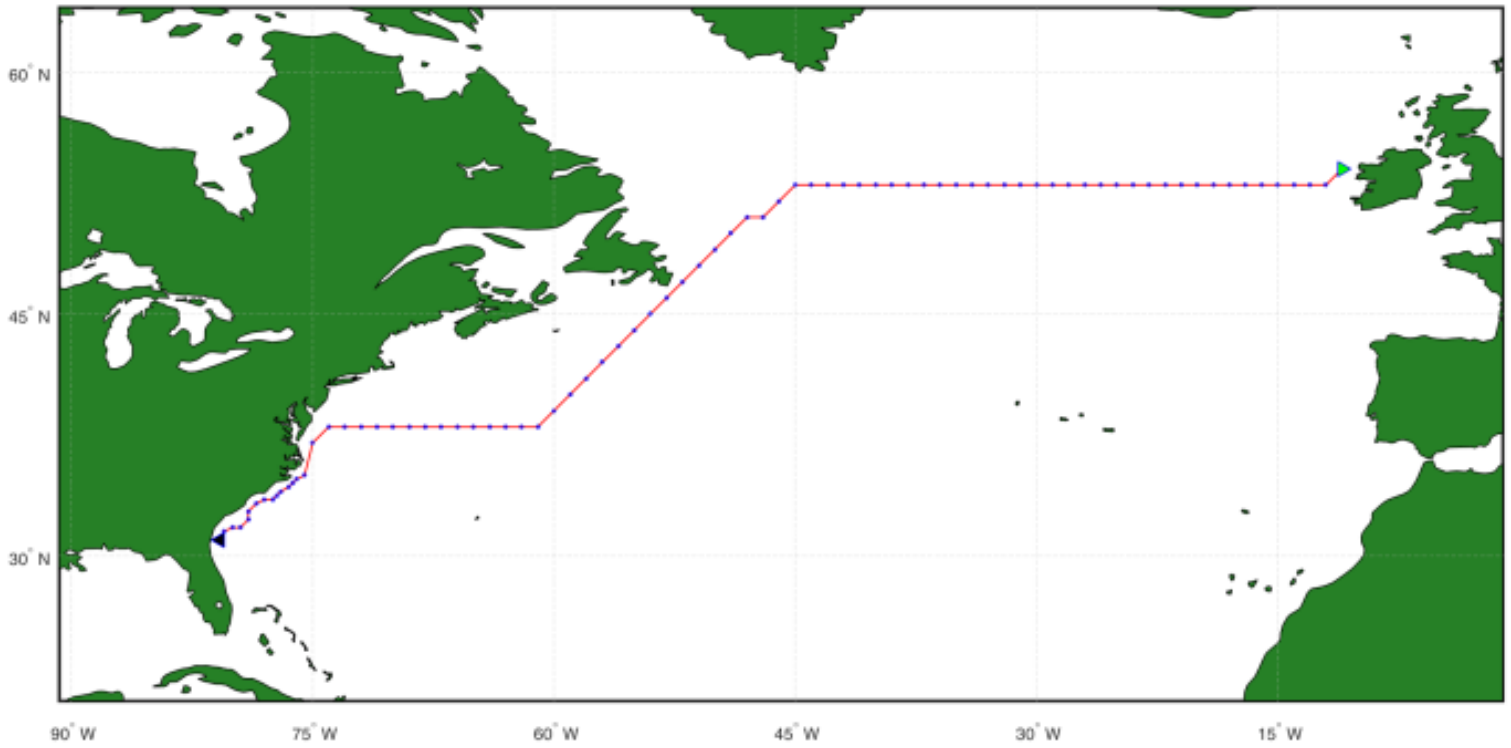
Vindskip™'s routing test

Route from Florida to Ireland



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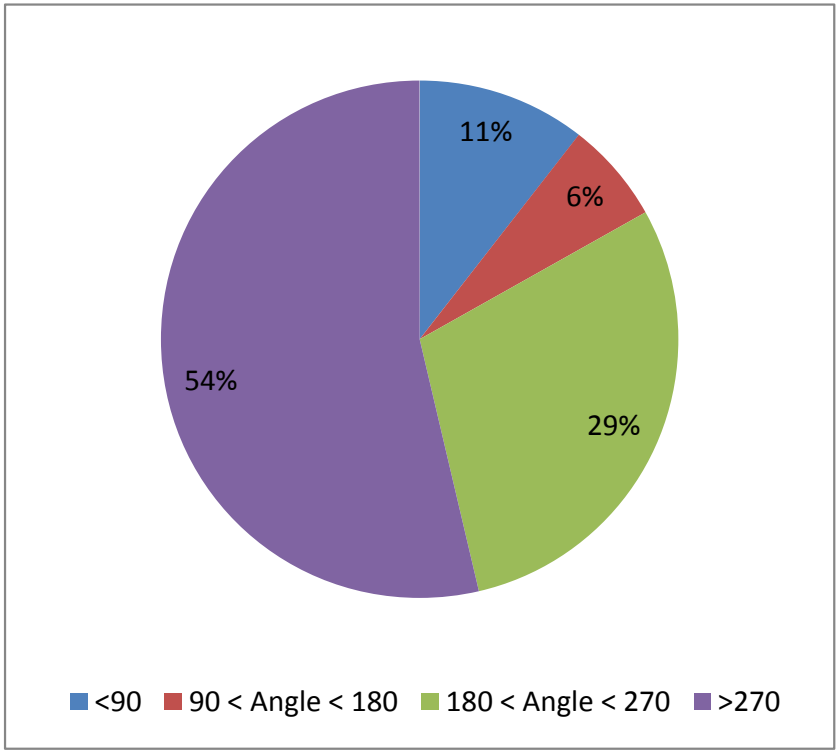

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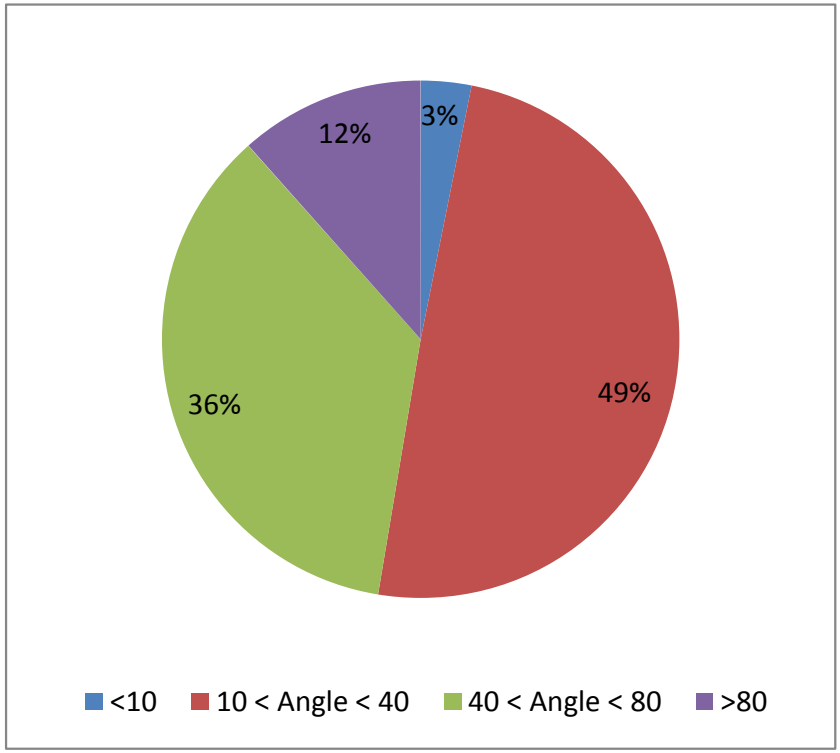

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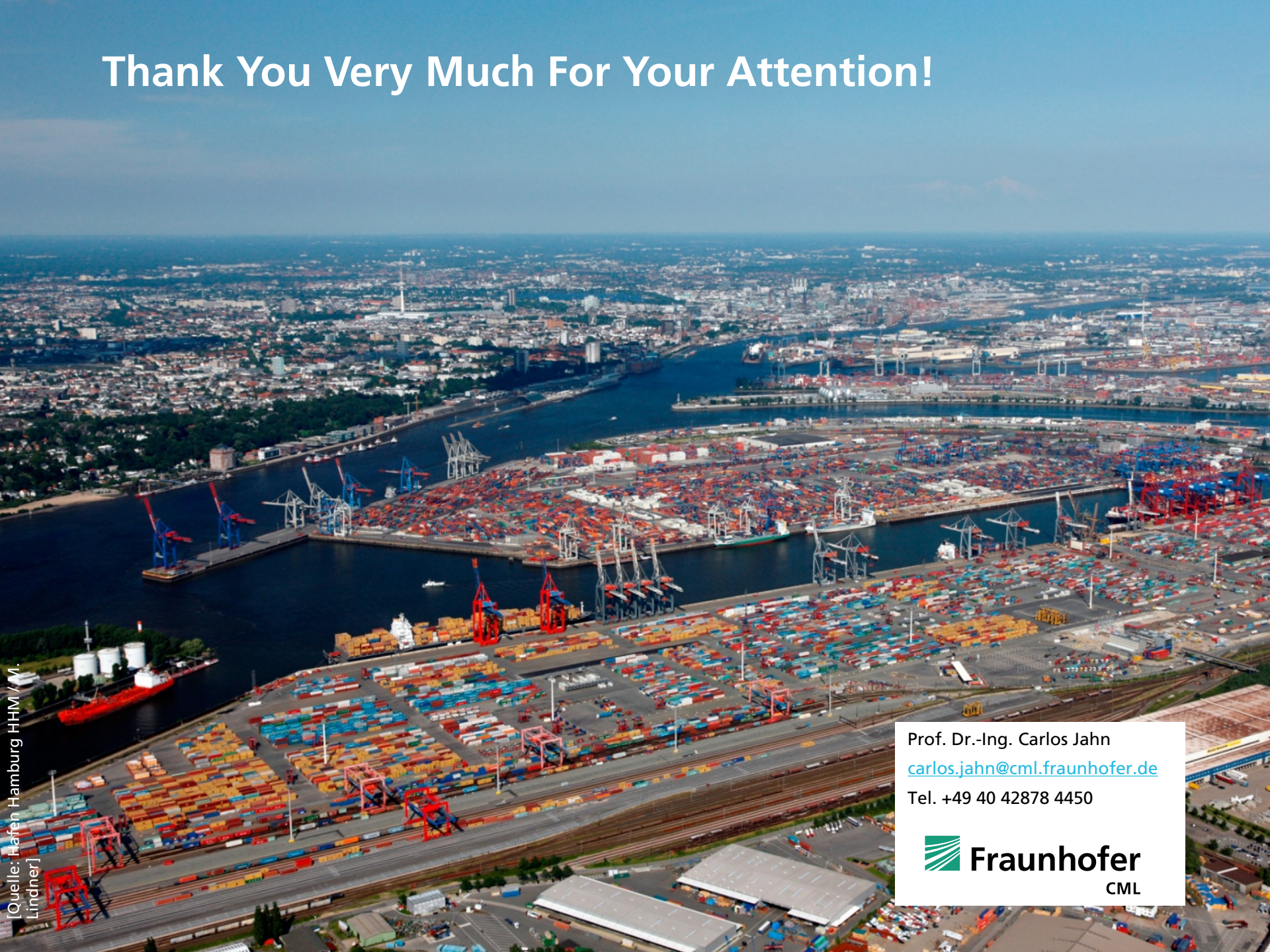
Conclusions

- MUNIN
  - Strategic routing can avoid strong winds and high waves
  - Operational routing can react according to weather situation
- Vindskip™
  - Optimal wind directions are favoured in route optimisation
  - Occurrence of unfavourable angles of attack minimised
- Further developments
  - Extensive testing and route smoothing to quantitatively assess the potential of the examined innovation ship concepts

Thank You Very Much For Your Attention!



[Quelle: Hafen Hamburg HHM / M. Lindner]

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