Towards an analytical tool assessing the operability of offshore personnel transfer limited by motion sickness

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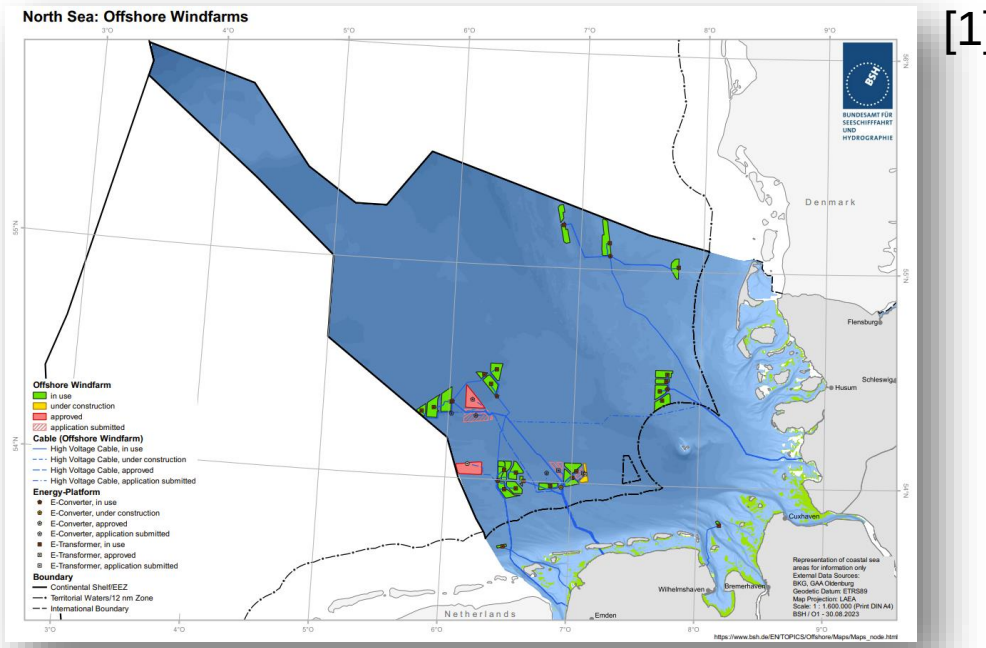
M.Sc. Lukas Fröhling
M.Sc. Thilo Grotebrune
Prof. Dr.-Ing. Arndt Hildebrandt

Ludwig-Franzius-Institute for Hydraulic, Estuarine and Coastal Engineering, Leibniz Universität Hannover,
www.lufi.uni-hannover.de, froehling@lufi.uni-hannover.de

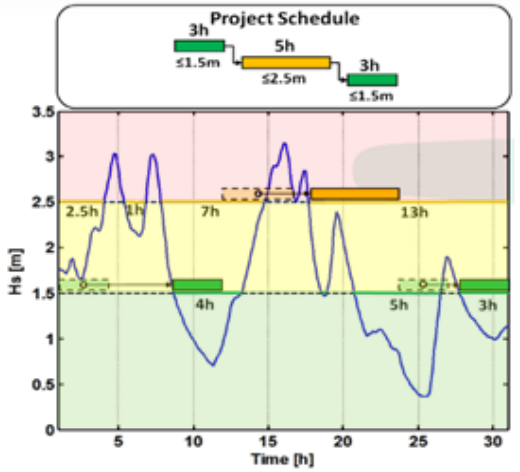
Introduction

- Over 20 OWP fully commissioned in the German EEZ with total capacity of ~8.5 GW (2023)
- Aim is to achieve a rated capacity of
  - 30GW by 2030
  - 70GW by 2045
- O&M costs make up around 30% of levelised costs of energy (CARROLL et al., 2016)
- Crew Transfer limited by
  - Environmental factors
  - Availability vessel & personnel
  - Physical Strain / *motion sickness*

➢ Assess operability based on motion sickness



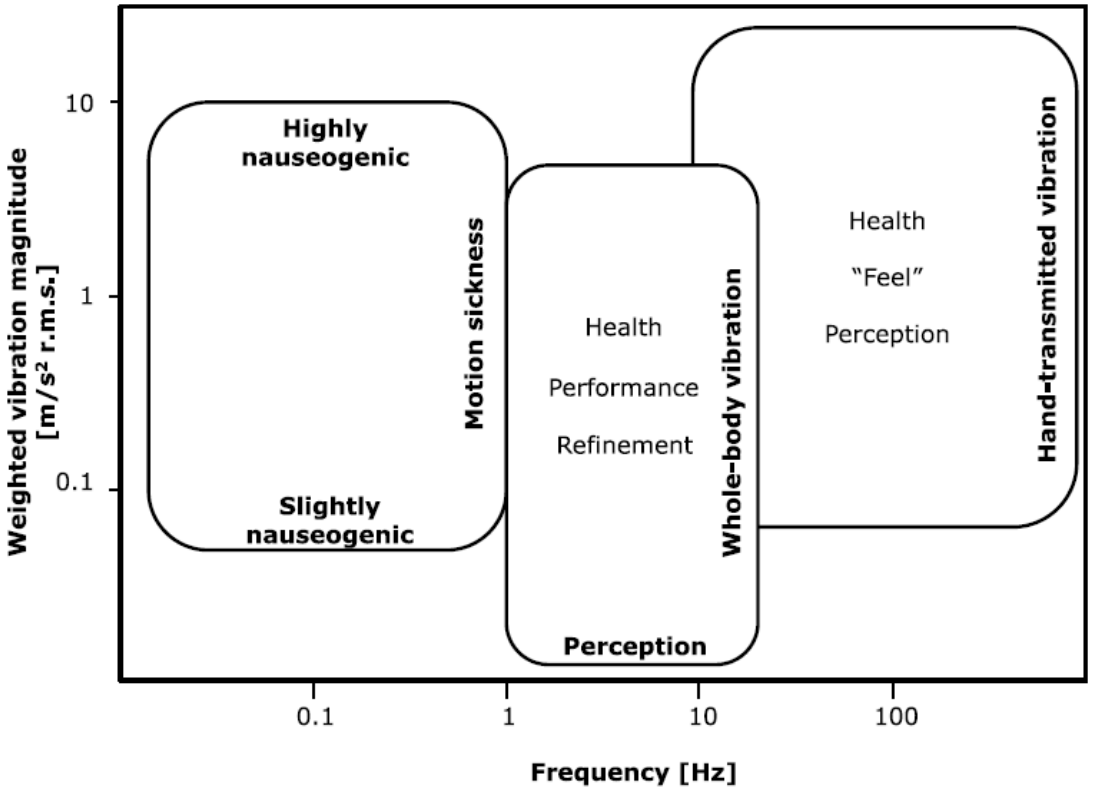
[1]



Human response to vibration

- According to MAIRITIME AND COASTGUARD AGENCY (2009), exposure to motion can be classified into following categories
  - Discomfort and adverse effects on performance
  - General health and safety risk
  - Aggravation of pre-existing injuries
  - Motion sickness (low-frequency motions)

- Classification of motions with respect to frequency and acceleration magnitude



[2]

Assessment of motions

- International (ISO 2631-1 & ISO 6897) and national standards (VDI 2057-1:2017-8) available for assessing motions in different environments

- Root-mean-square values of vertical acceleration used for evaluation

$$rms = \sqrt{\frac{1}{n}\sum_{i=1}^{n} x_i^2}$$

- Frequency weighting connects information about the subjective human response to different vibration properties

VDI 2057-1:2017-8

r.m.s. of frequency weighted acceleration a_{W_KT} [m/s²]	*Description of perception under sinusoidal stimuli*
< 0.01	Not perceptible
0.015	Threshold of perception
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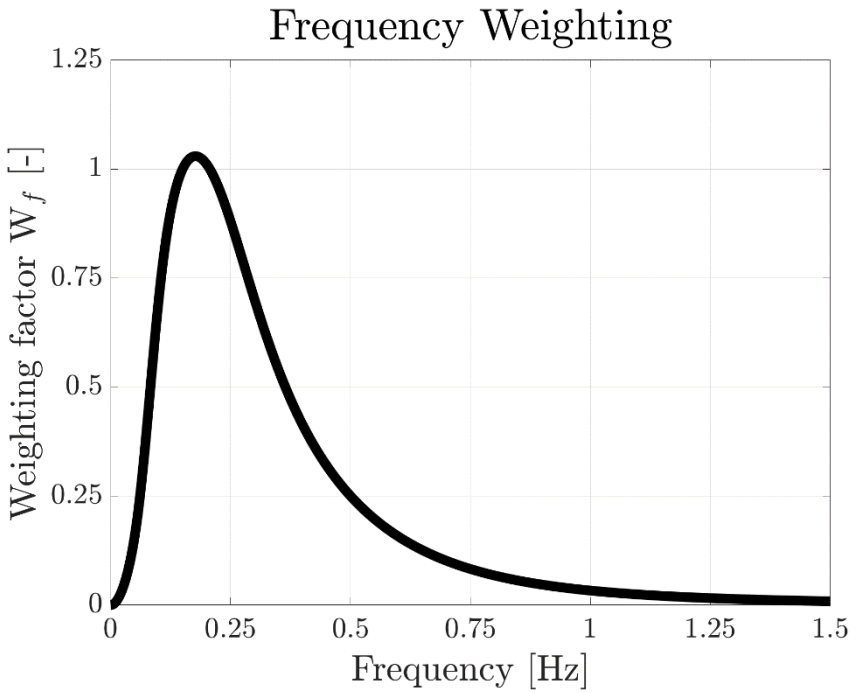


Tool Workflow

Vessel Tour Information

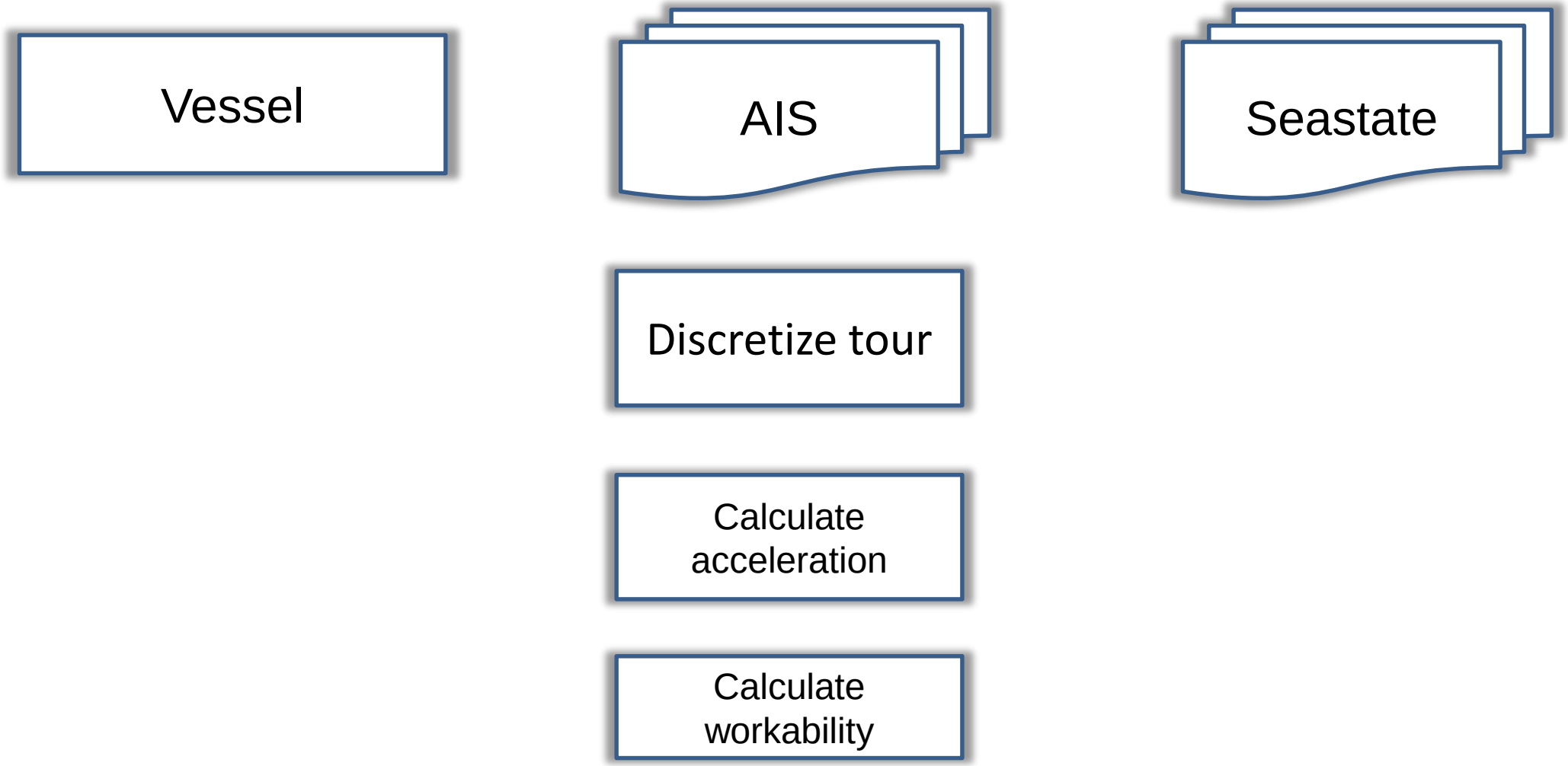
Historical Seastate

Seastate Projections

Analytical Tool

?

Tool Workflow

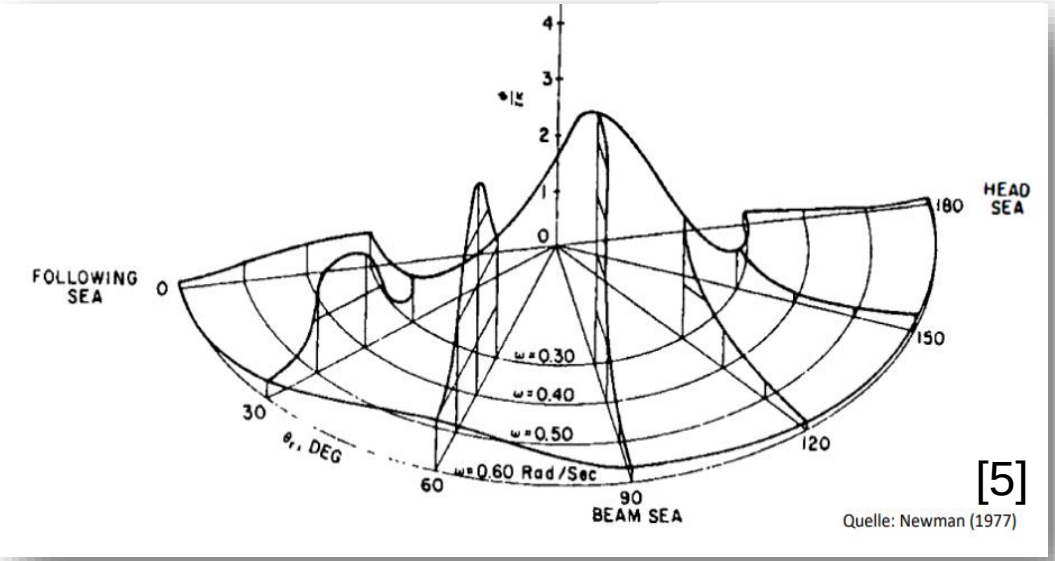


Tool Workflow

Vessel

- Dimensions (Length, Width)
- Positions on vessel at which accelerations are evaluated
- Motion characteristics (RAO)

[4]



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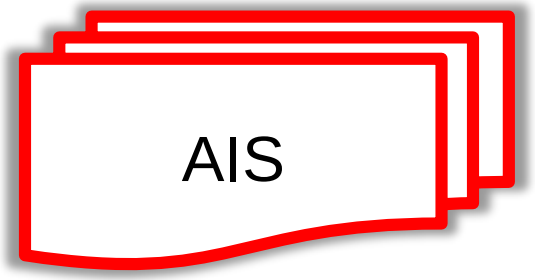
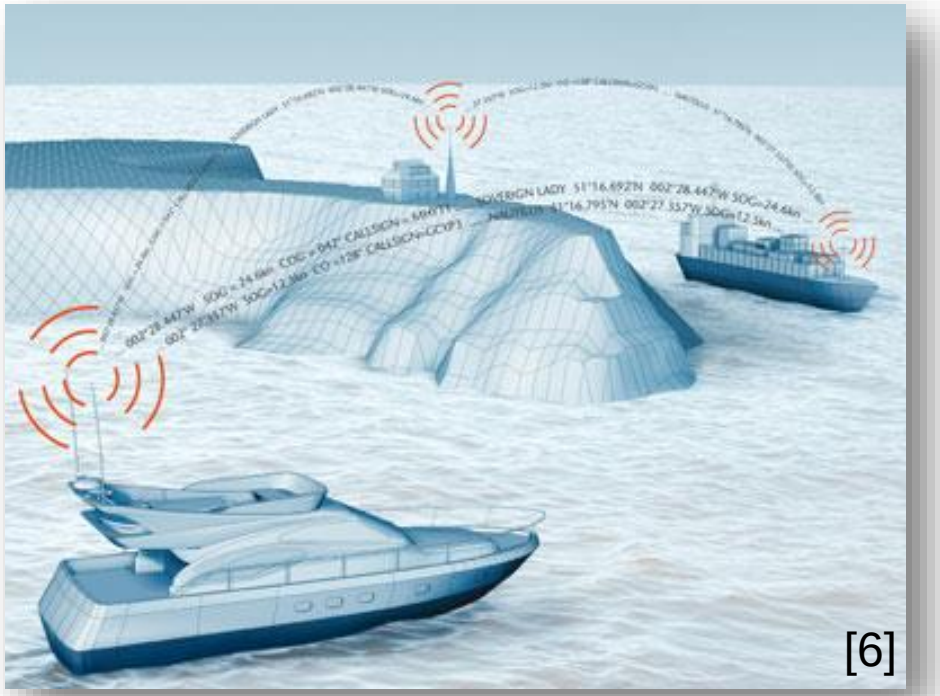
Tool Workflow

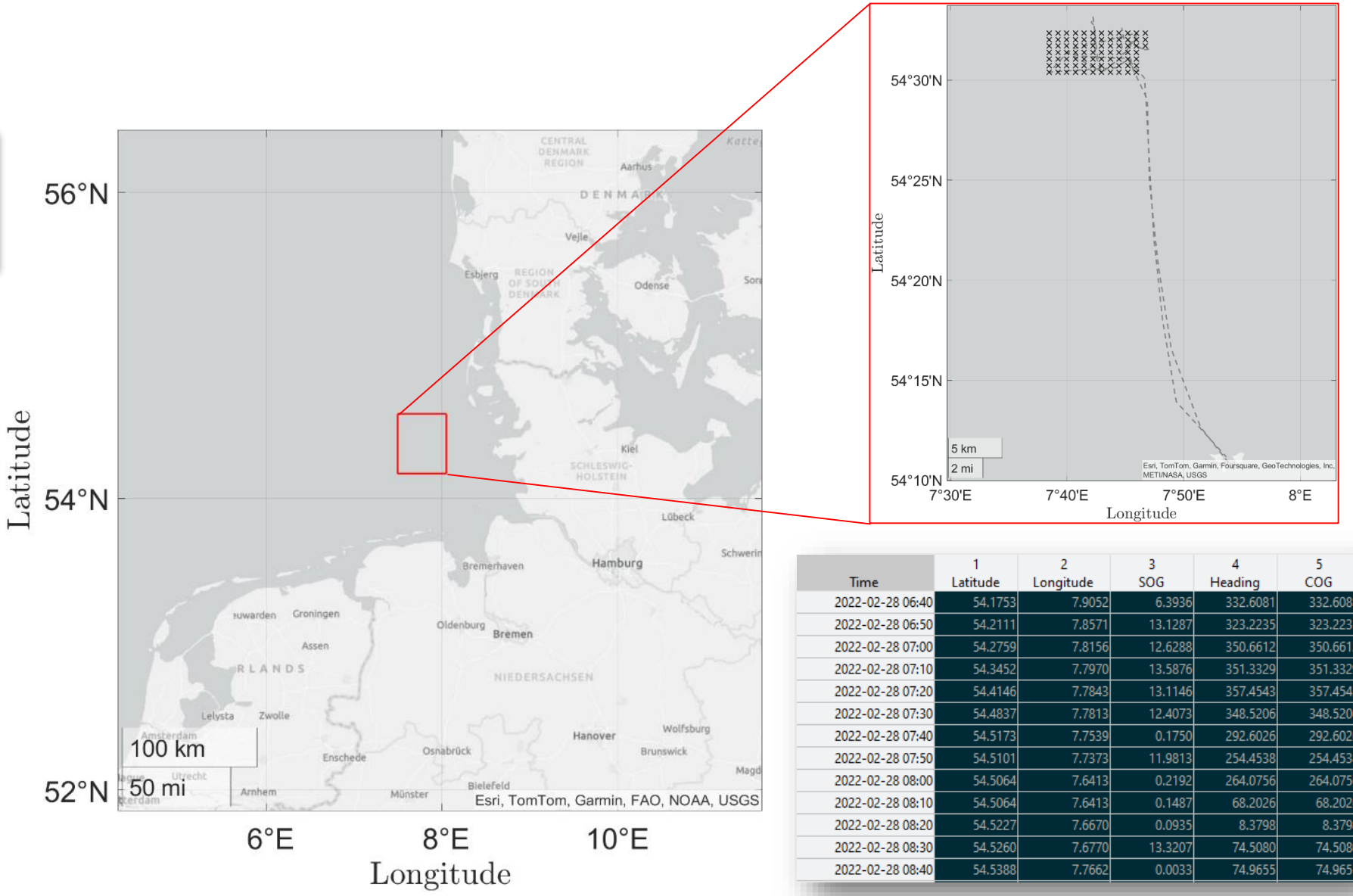




- Automatic Identification System provide identification and positioning information
  - Static & Voyage related information (IMO/MMSI, Type, Dimension, Destination, ...)
  - Dynamic Information (Time, Latitude/Longitude, Speed, CoG, Heading)

Tool Workflow

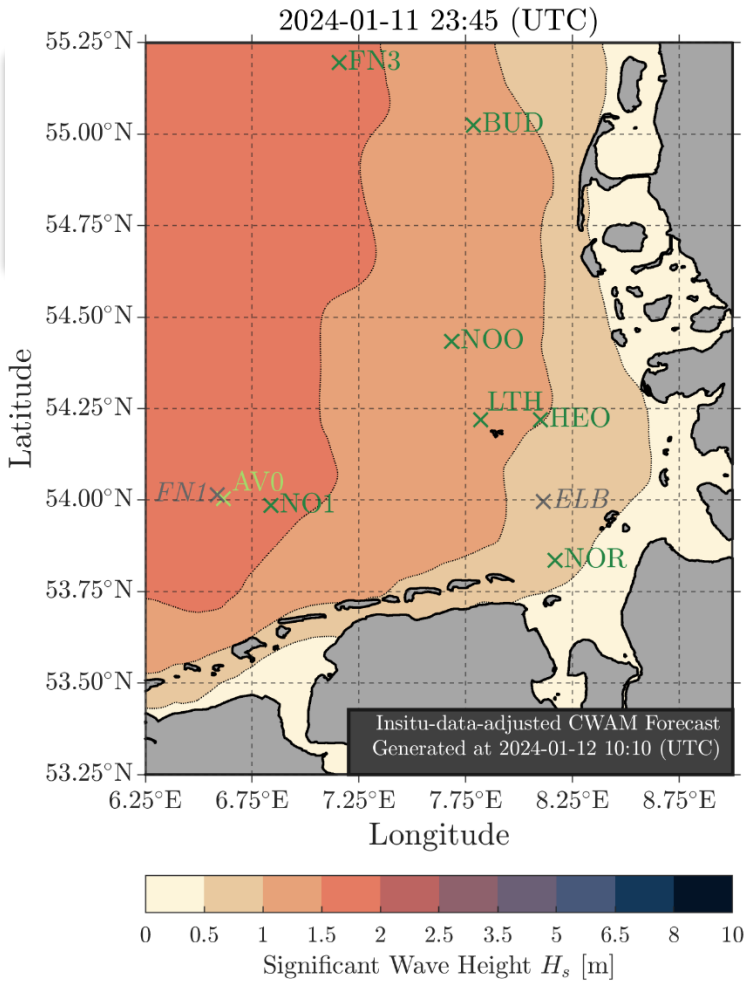
AIS



Time	1 Latitude	2 Longitude	3 SOG	4 Heading	5 COG
2022-02-28 06:40	54.1753	7.9052	6.3936	332.6081	332.6081
2022-02-28 06:50	54.2111	7.8571	13.1287	323.2235	323.2235
2022-02-28 07:00	54.2759	7.8156	12.6288	350.6612	350.6612
2022-02-28 07:10	54.3452	7.7970	13.5876	351.3329	351.3329
2022-02-28 07:20	54.4146	7.7843	13.1146	357.4543	357.4543
2022-02-28 07:30	54.4837	7.7813	12.4073	348.5206	348.5206
2022-02-28 07:40	54.5173	7.7539	0.1750	292.6026	292.6026
2022-02-28 07:50	54.5101	7.7373	11.9813	254.4538	254.4538
2022-02-28 08:00	54.5064	7.6413	0.2192	264.0756	264.0756
2022-02-28 08:10	54.5064	7.6413	0.1487	68.2026	68.2026
2022-02-28 08:20	54.5227	7.6670	0.0935	8.3798	8.3798
2022-02-28 08:30	54.5260	7.6770	13.3207	74.5080	74.5080
2022-02-28 08:40	54.5388	7.7662	0.0033	74.9655	74.9655

Tool Workflow

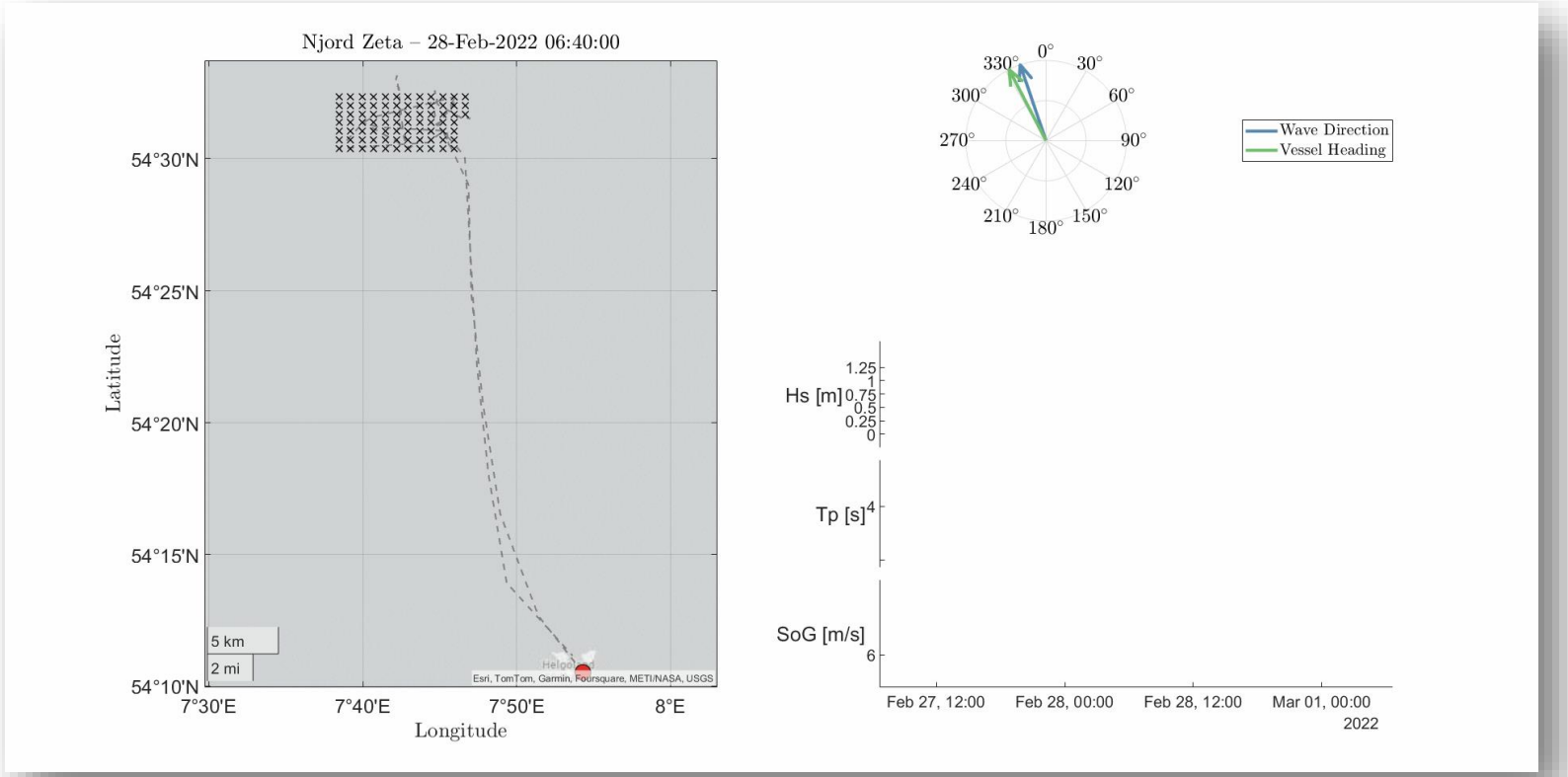
- Information regarding wave height, period and direction for period of vessel tour
- Spatial hindcast or forecast data



Tool Workflow

Discretize tour

- Merge AIS and seastate data inputs and discretize tour with constant timestep $\Delta t = 10\,\mathrm{min}$



Tool Workflow

Calculate acceleration

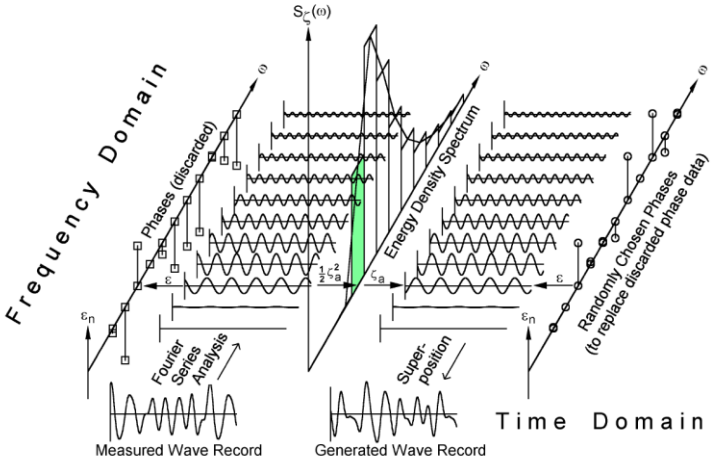
For each sample Δt:

- Wave spectrum based on Hs and Tp
- Vessel response (heave, roll, pitch) spectrum
- Adjust response spectra based on vessel speed
- Calculate timeseries of combined vertical displacement and acceleration
- Acceleration spectrum and apply frequency weighting
- Create final timeseries for weighted vertical acceleration
- Determination of rms acceleration value for current sample

Tool Workflow

Calculate acceleration

$$S_\zeta(\omega) \cdot d\omega = \frac{1}{2}\zeta_a^2(\omega)$$



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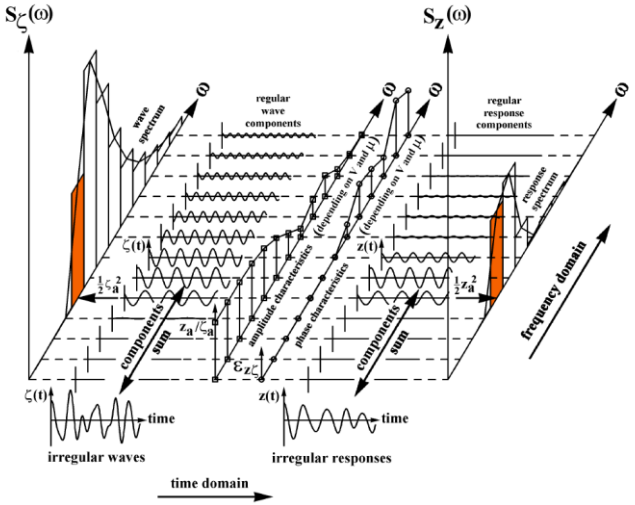
Calculate acceleration

$$S_z(\omega) = \left| \frac{z_a}{\zeta_a}(\omega) \right|^2 \cdot S_\zeta(\omega)$$



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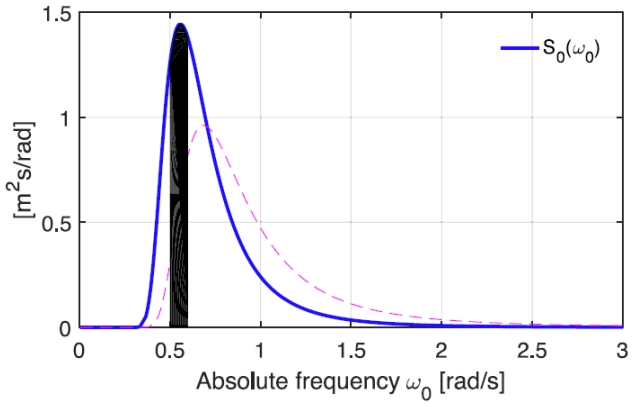

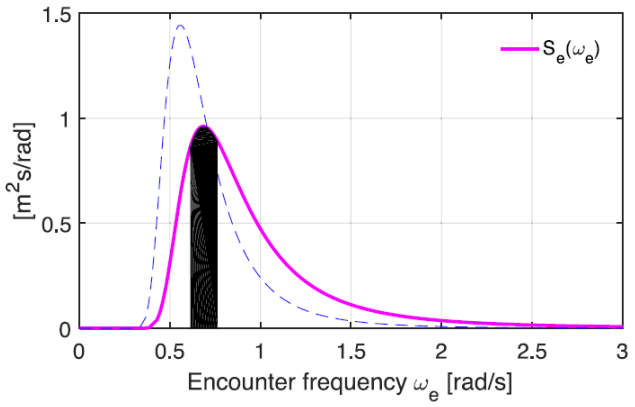

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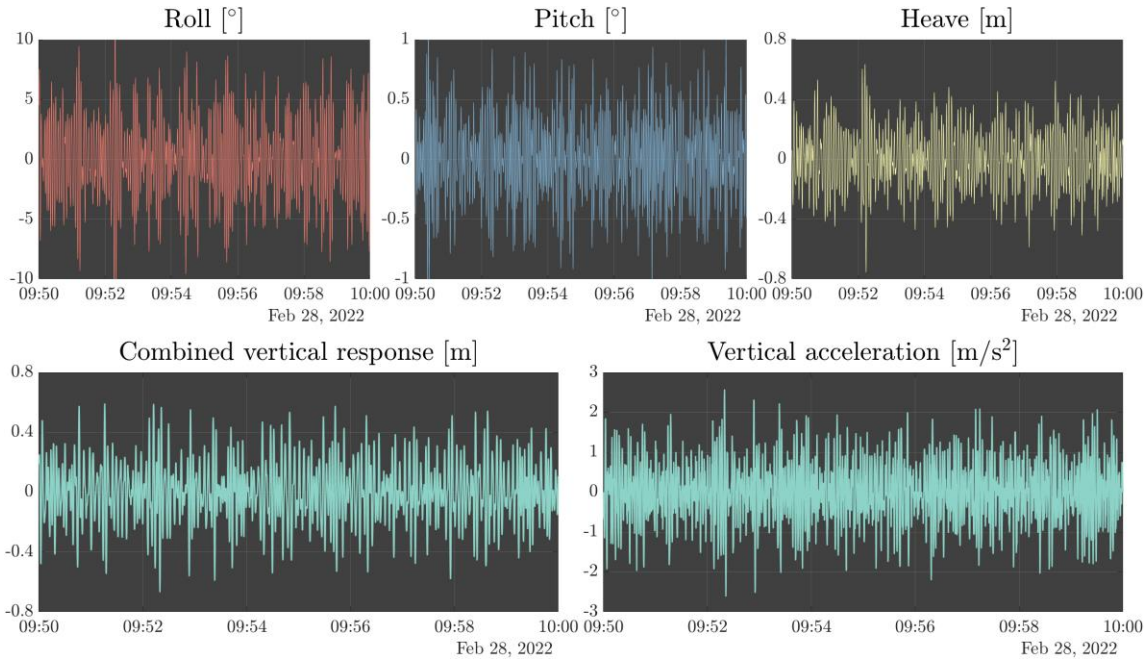

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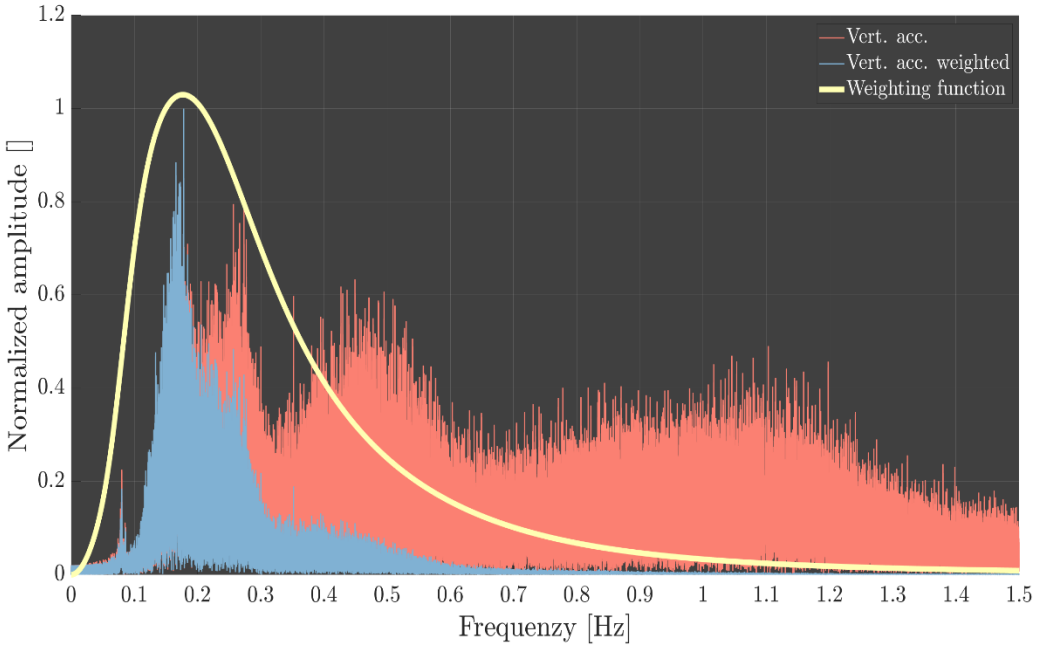

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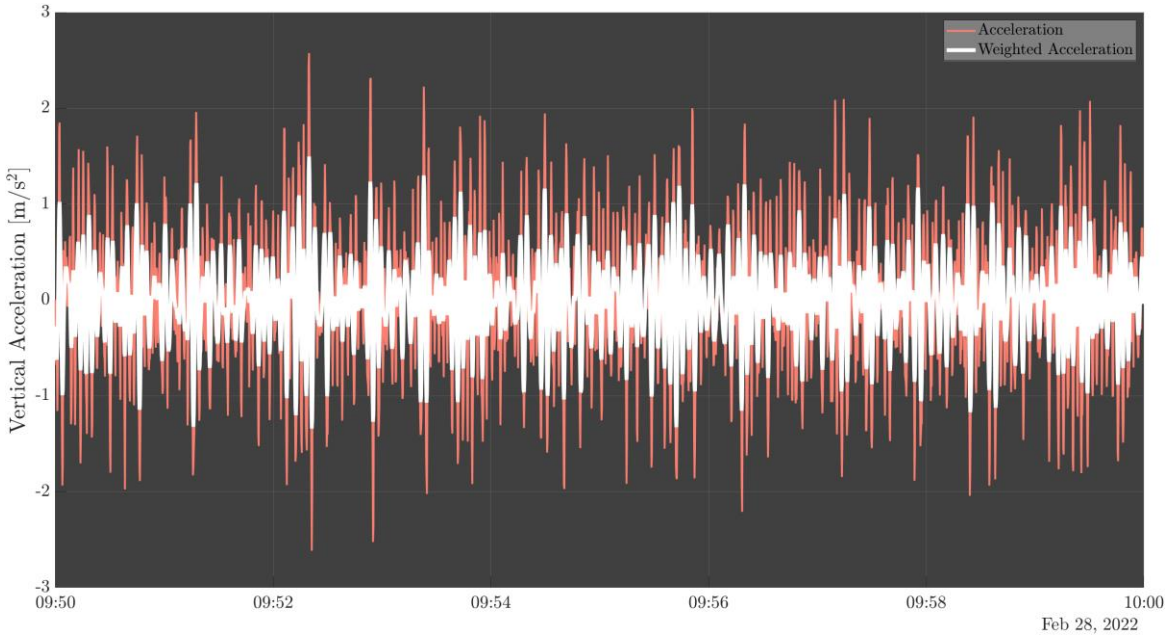

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$$rms = \sqrt{\frac{1}{n}\sum_{i=1}^{n} a_{z,weighted}{}_i^2}$$

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Tool Workflow

Calculate workability

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[3]

- Define acceleration threshold
- Calculate Workability Index WI Scheu et al. (2018)

$$WI = \frac{Number\ of\ samples < Threshold}{Total\ number\ of\ samples}$$

- One value describes tour operability based on acceleration

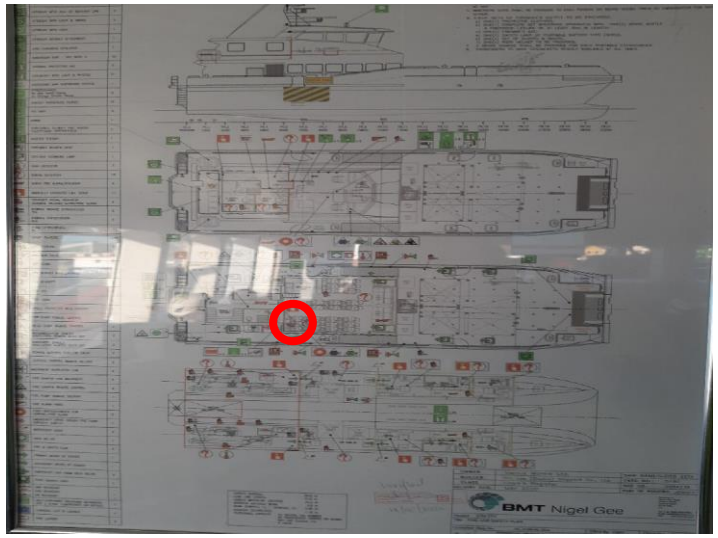
WI = 0 — WI = 1.0

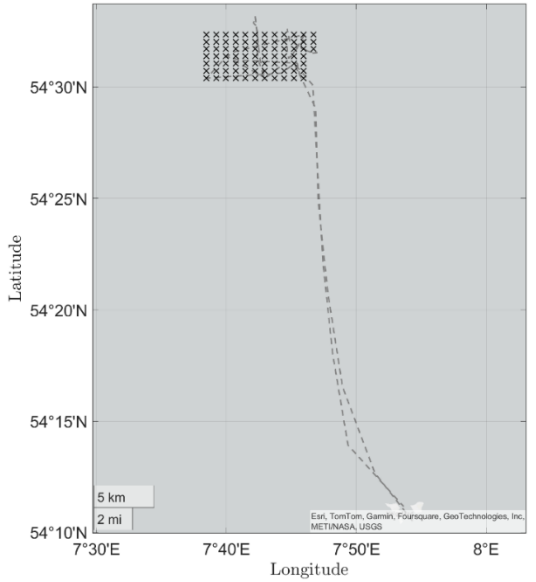
Tool validation

- „Measuring Box“ developed by Woelfel in the framework of research project AVIMo (FKZ: 0324350A)

- GPS and acceleration sensors measure position, speed and resulting (x,y,z) acceleration at high sample rate

➢ On vessel for Helgoland – Amrumbank West tour





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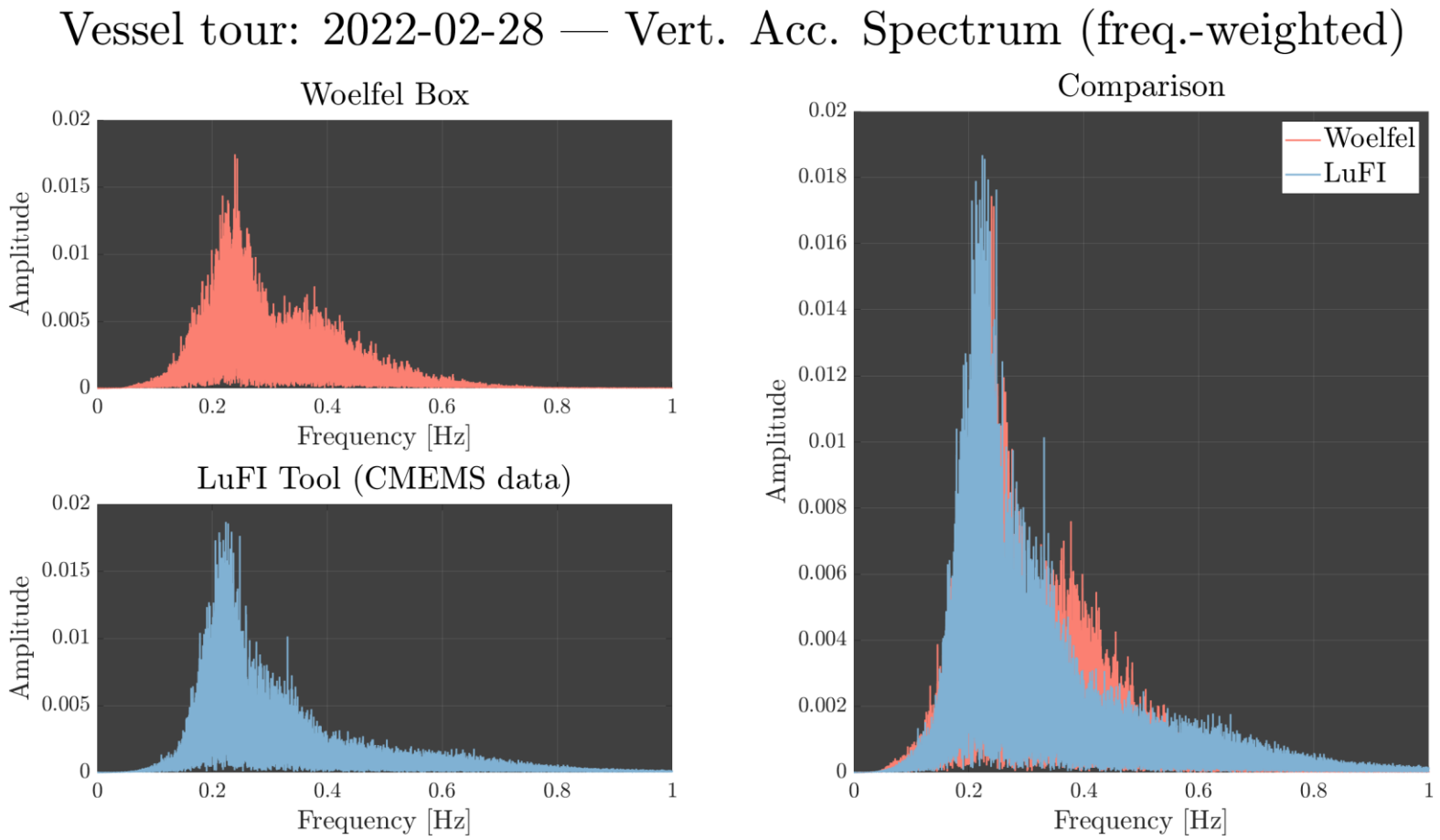
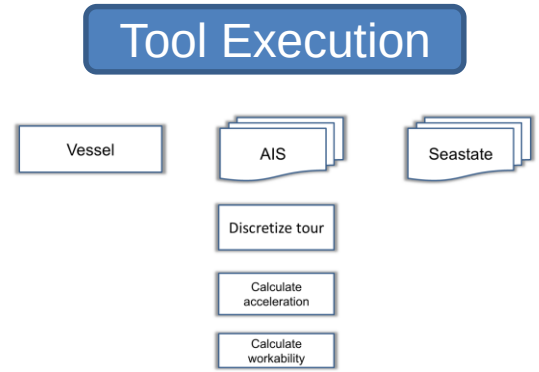


Calculate operability based on 40 year hindcast data



- CMEMS Hindcast dataset Atlantic- European North West Shelf- Wave Physics Reanalysis provides historical seastate information
- Tool Execution for each day between 1980-01-01 and 2022-12-01

1980-01-01 Tool Execution

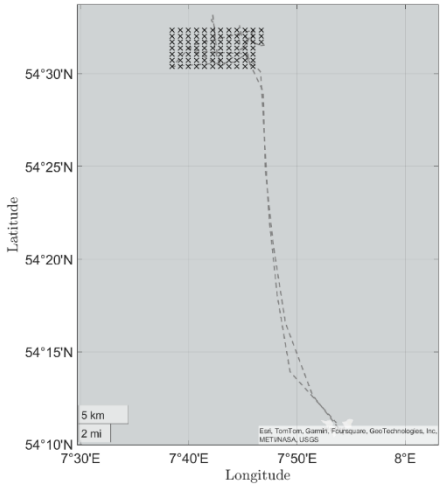
⋮

2022-02-27 Tool Execution

2022-02-28 Tool Execution

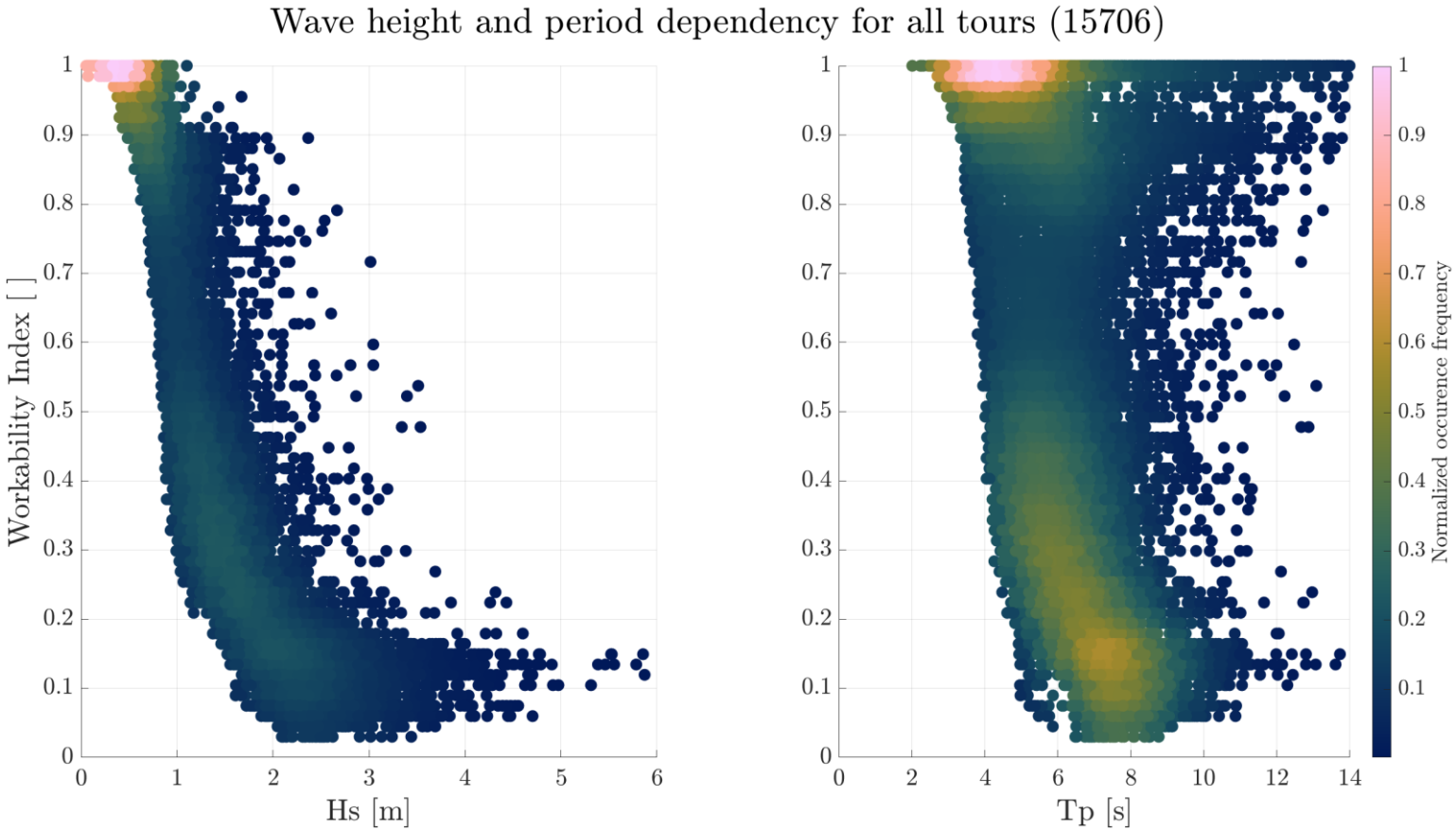
⋮

2022-12-31 Tool Execution



Vessel tour evaluated at ~15.700 days

Calculate operability based on 40 year hindcast data



How to assess the operability?

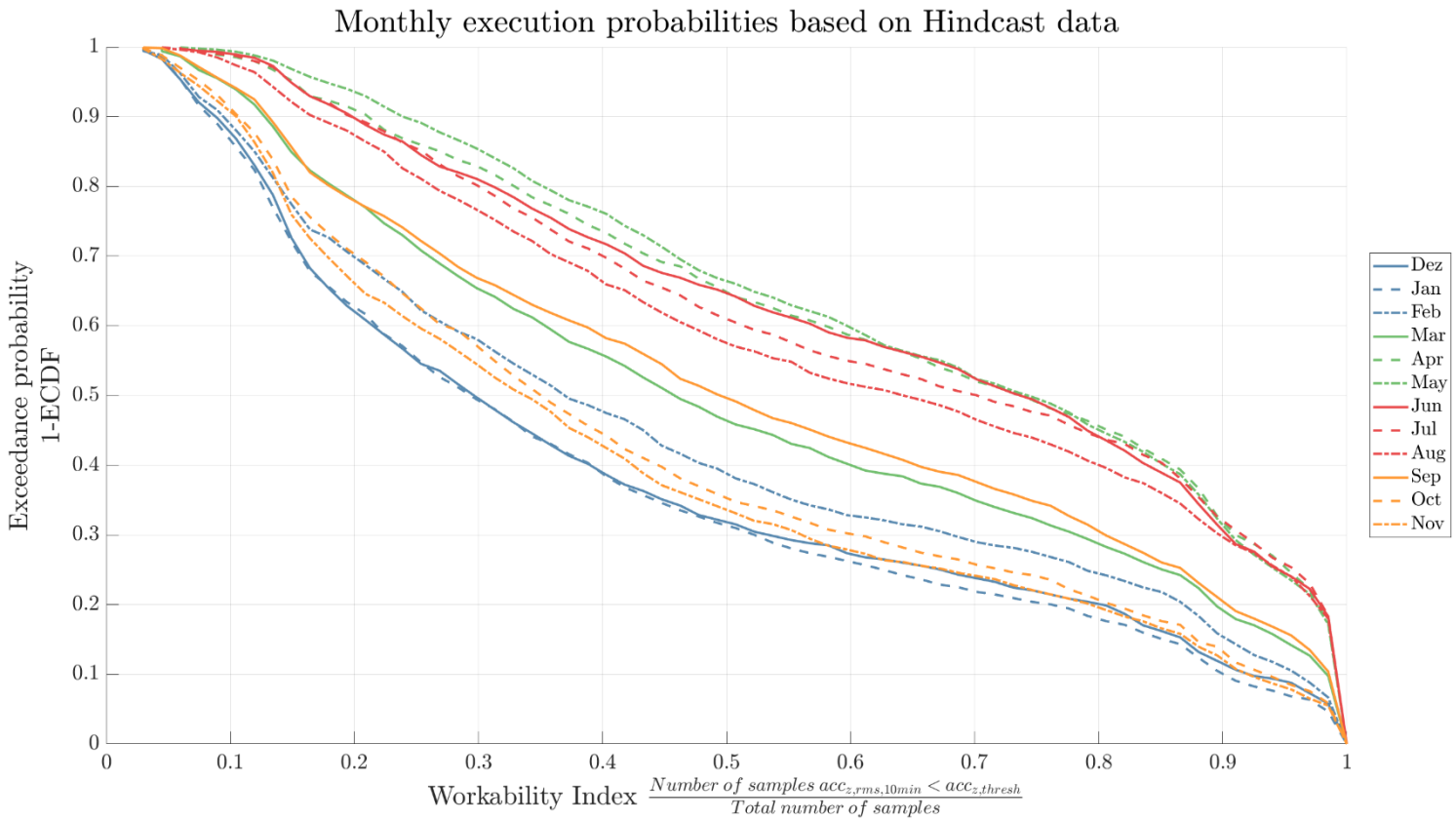
Assessing the offshore operability

- Empirical Cumulative Distribution Function (ECDF)

$$ECDF = \frac{1}{n}\sum_{i=1}^{n} x_i \leq t$$

- Cluster WI data in the months in which tours took place

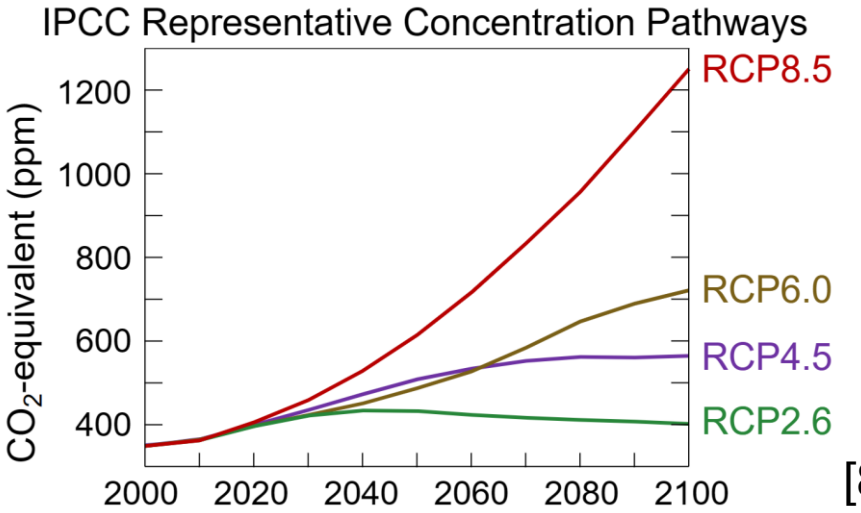
- *1 – ECDF* to visualize Exceedance Probability of given WI



How will the operability adapt due to climate change?

- Four Represantive Concentration Pathways (RCP) were used for climate modeling for 2014 IPCC report
  - RCP4.5: „Optimitistic“ scenario
  - RCP8.5: business as usual

- ECMWF Ocean Wave Time Series [9] for the European Coast derived from climate projections (RCP4.5 & RCP8.5) available for 2041-2100



[8]

How will the operability adapt due to climate change?

- Apply tool on ECMWF dataset

  2041-01-01 **Tool Execution**

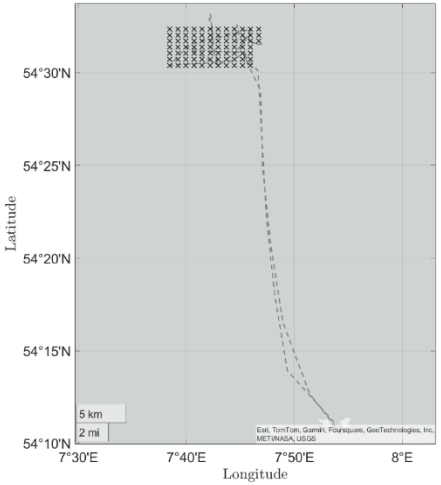
  ⋮

  2100-12-31 **Tool Execution**

- Calculate *50th percentile WI* for each month

- Compare CMEMS, RCP4.5 & RCP8.5 probabilities

➢ Operability will decrease up to 10%!



Vessel tour evaluated at ~21.900 days

How will the operability adapt due to climate change?

- Apply tool on ECMWF dataset

  2041-01-01 **Tool Execution**

  ⋮

  2100-12-31 **Tool Execution**

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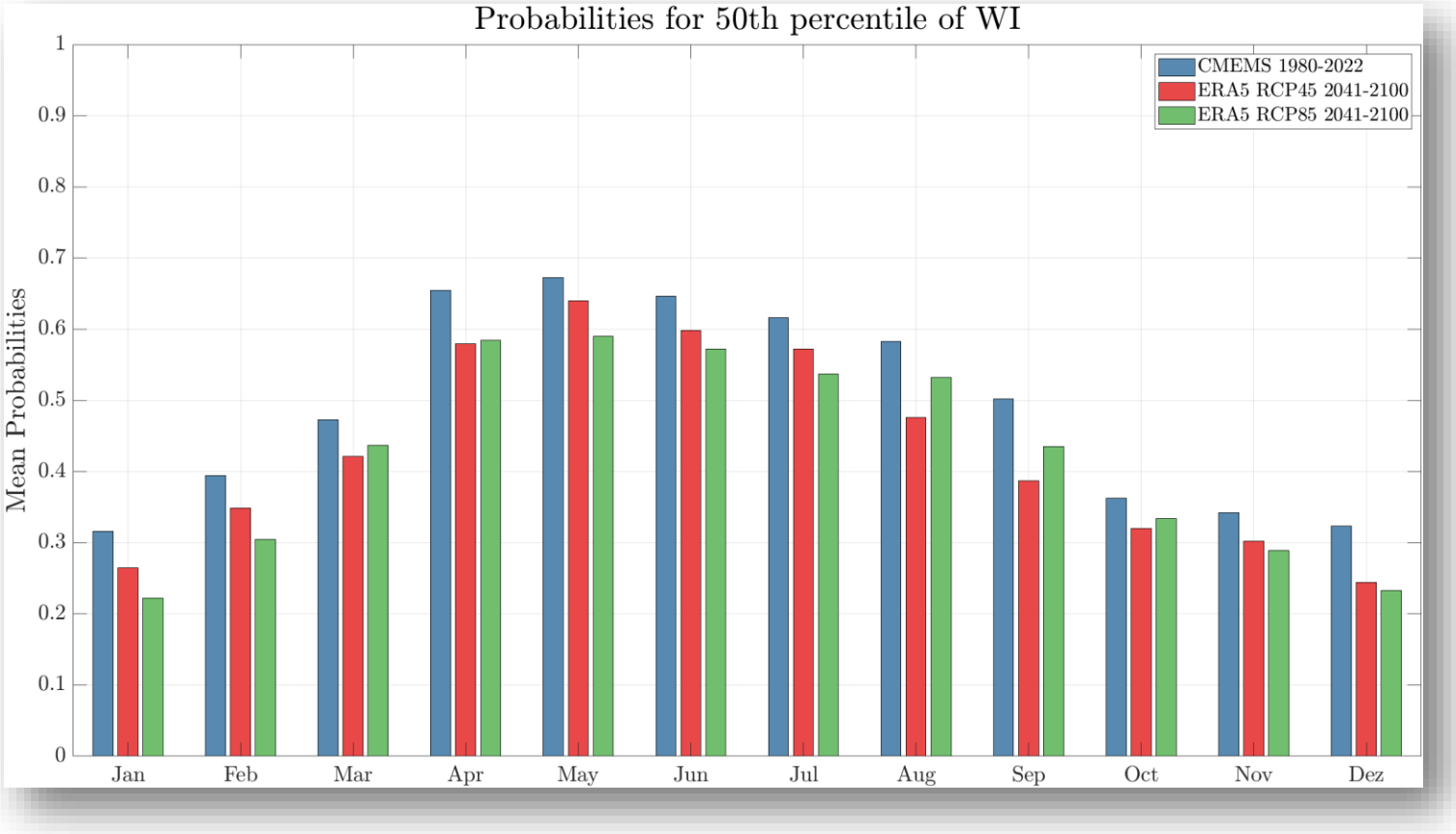

Conclusion

- Assessment of vessel tour operability via analytical tool
- Can be applied to any vessel and any route
- Monthly execution probabilities based on hindcast data
- Climate change will lead to reduced operability

Literature

[1] North Sea: Offshore Windfarms, https://www.bsh.de/EN/TOPICS/Offshore/Maps/_Anlagen/Downloads/NorthSea_OffshoreWindfarms.pdf?__blob=publicationFile&v=20, accessed February 2024

[2] Mansfield, N. J. (2004). Human Response to Vibration (N. J. Mansfield, Ed.). CRC Press. https://doi.org/10.1201/b12481

[3] VDI 2057-1:2017-8, Human exposure to mechanical vibrations: Whole body vibration

[4] DAMEN, Fast Crew Supplier 2610, https://www.damen.com/services/damen-trading/used-vessels/crewboat/fast-crew-supplier-2610-for-charter-07706, accessed February 2024

[5] Newman, J. N. (1977). Marine Hydrodynamics. MIT Press

[6] International Maritime Organization (2019), https://www.imo.org/en/OurWork/Safety/Pages/AIS.aspx, assessed March 2024

[7] Nielsen, U. D. (2017). Transformation of a wave energy spectrum from encounter to absolute domain when observing from an advancing ship. In Applied Ocean Research (Vol. 69, pp. 160–172). Elsevier BV. https://doi.org/10.1016/j.apor.2017.10.011

[8] IPCC, 2014: *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

[9] Copernicus Climate Change Service. (2019). Ocean surface wave time series for the European coast from 1976 to 2100 derived from climate projections [dataset]. ECMWF. https://doi.org/10.24381/CDS.572BF3822

Fraunhofer IWES

BUNDESAMT FÜR SEESCHIFFFAHRT UND HYDROGRAPHIE

Thank you!

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Forschungszentrum Jülich

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