

A Method to Estimate Emissions of an Inland Waterway Ship Maneuvering in Restricted Waters

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Outline

Motivation

Procedure

Experimental and Numerical Method

Emission Modeling

Results and Discussion

Conclusions

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- Predict the contribution of emissions from inland shipping on the Rhine river.



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- How does maneuvering situations influence the ship-induced emissions?



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- Predict the contribution of emissions from inland shipping on the Rhine river.
- How does maneuvering situations influence the ship-induced emissions?
- Missing of mathematical maneuvering models to predict the ship-induced emissions.



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Procedure

- Full-scale measurement: Operational data and emissions.



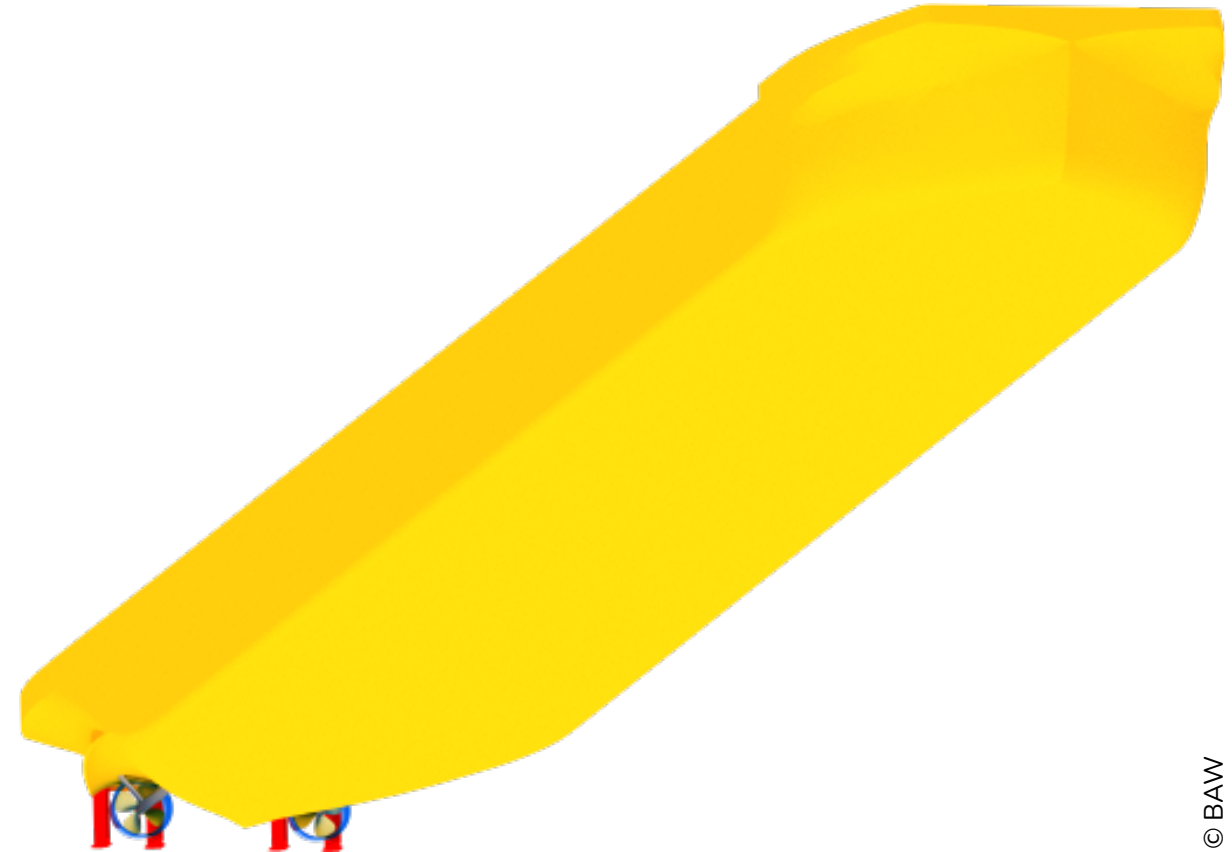
Procedure

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- Numerical methods: Validation with model scale and adaption for full-scale.



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- Numerical methods: Validation with model scale and adaption for full-scale.
- Mathematical models: Prediction of engine brake power and emission modeling.



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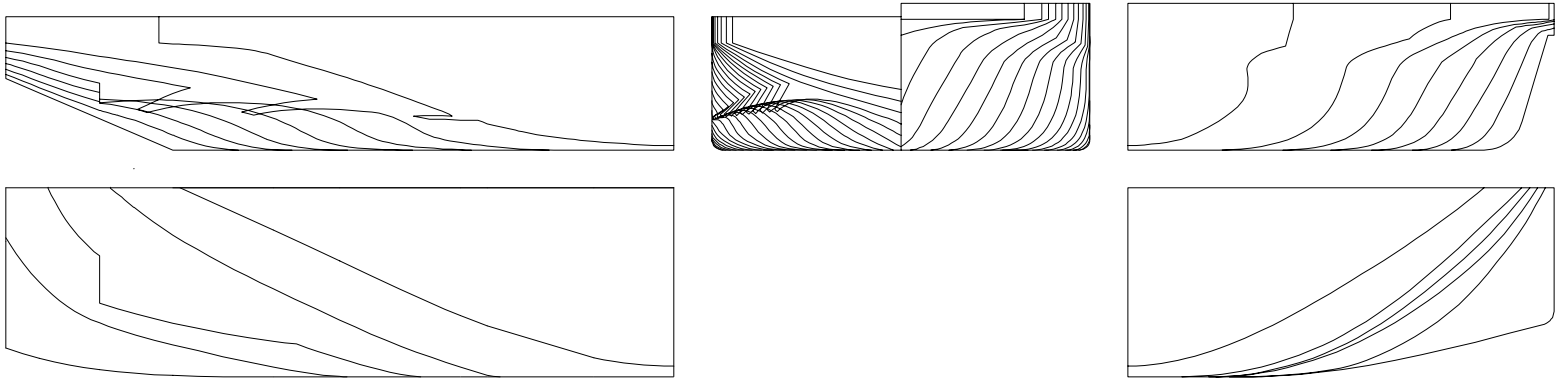
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Test Case

Main characteristics of the GMS Monika Deymann in full scale and model scale.

Description	Parameter	Unit	Full scale	Model scale
Scale factor	λ	—	1.00	17.00
Length overall	L_{OA}	m	135.00	7.941
Length between perpendiculars	L_{PP}	m	134.62	7.919
Breadth	B	m	14.15	0.832
Mean draft	T	m	1.70	0.10
Block coefficient	C_B	—	0.881	0.881



Lines plan of the Monika Deymann in bare hull configuration.

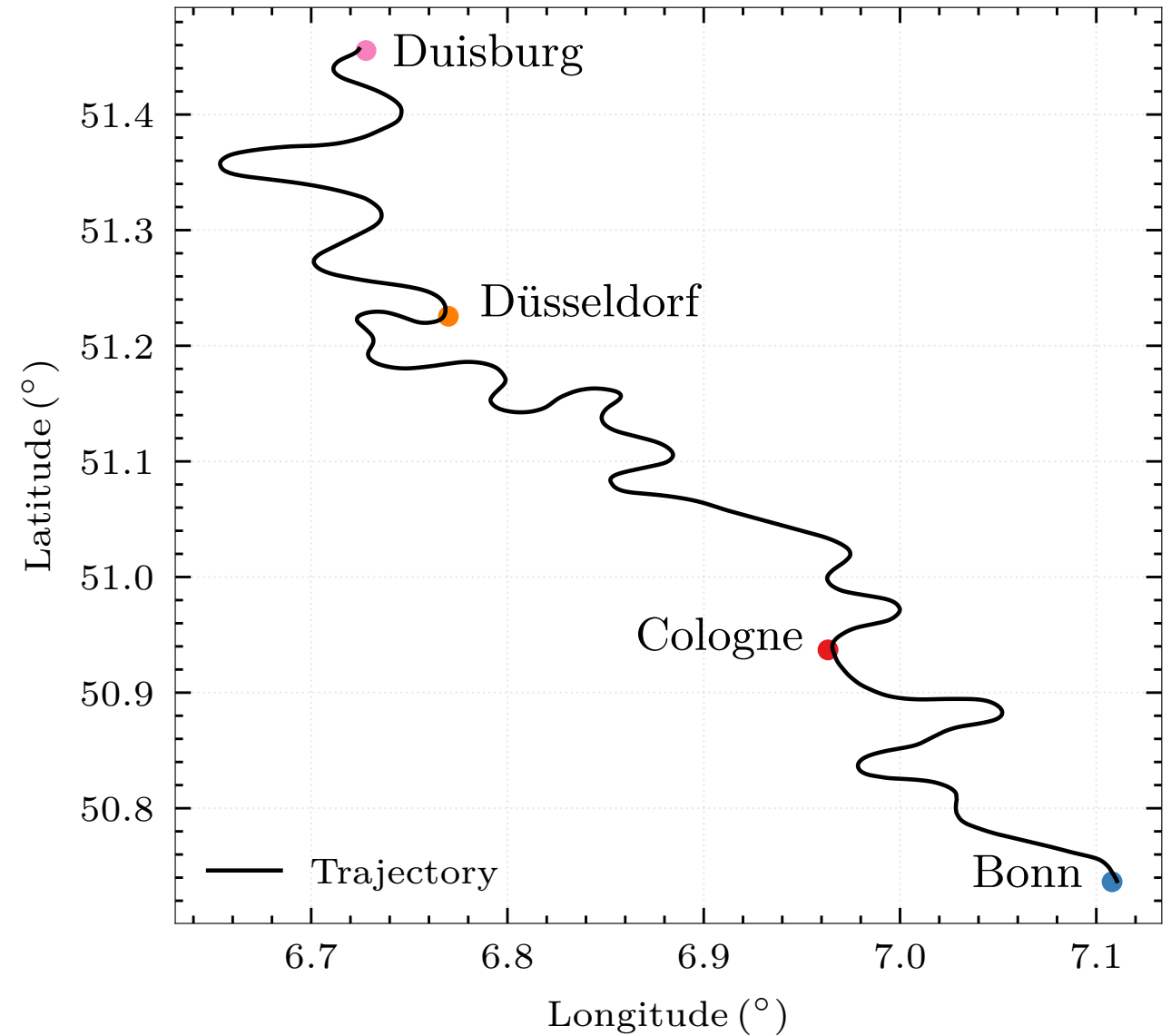
On-board Emission Measurement

- Trip:
 - Real-driving measurement while regular sailing.



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 - Two engines with 1030 kW each.



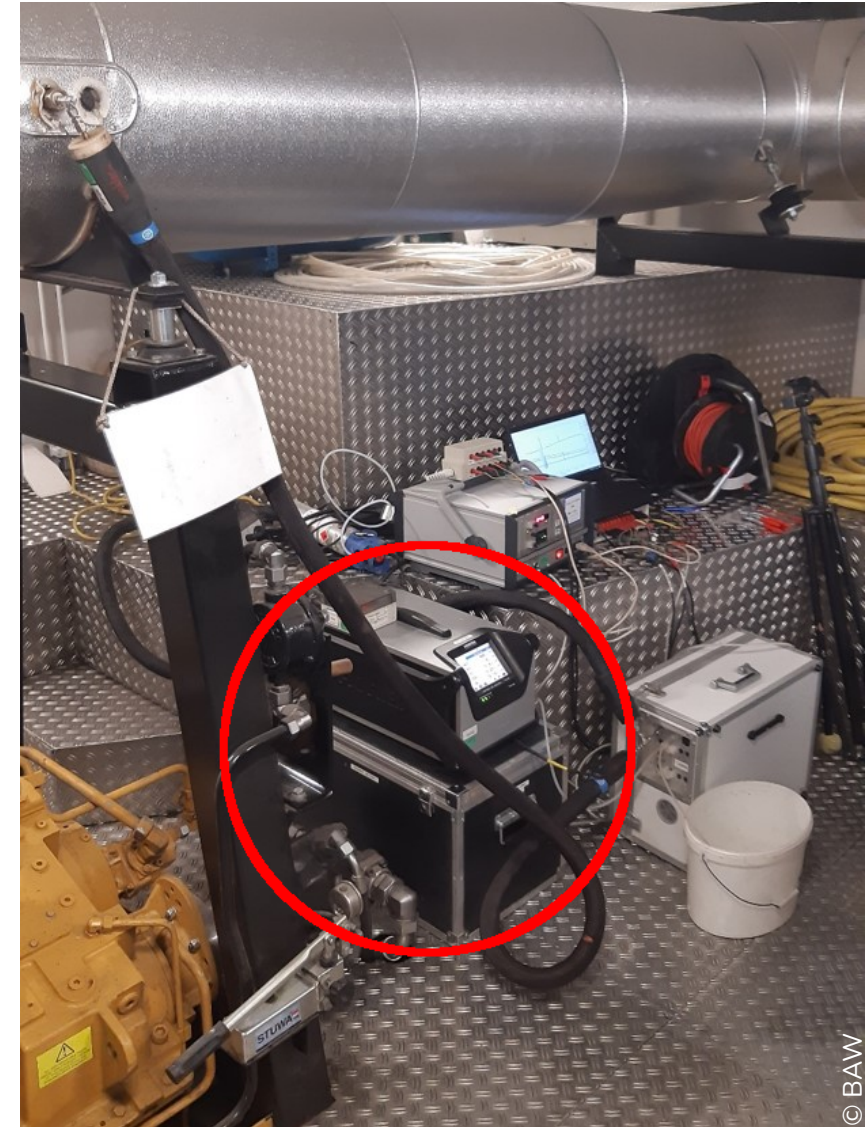
On-board Emission Measurement

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- Technical specifications:
 - Two engines with 1030 kW each.
 - Equipped with 2 ducted propellers and 2 twin rudders.



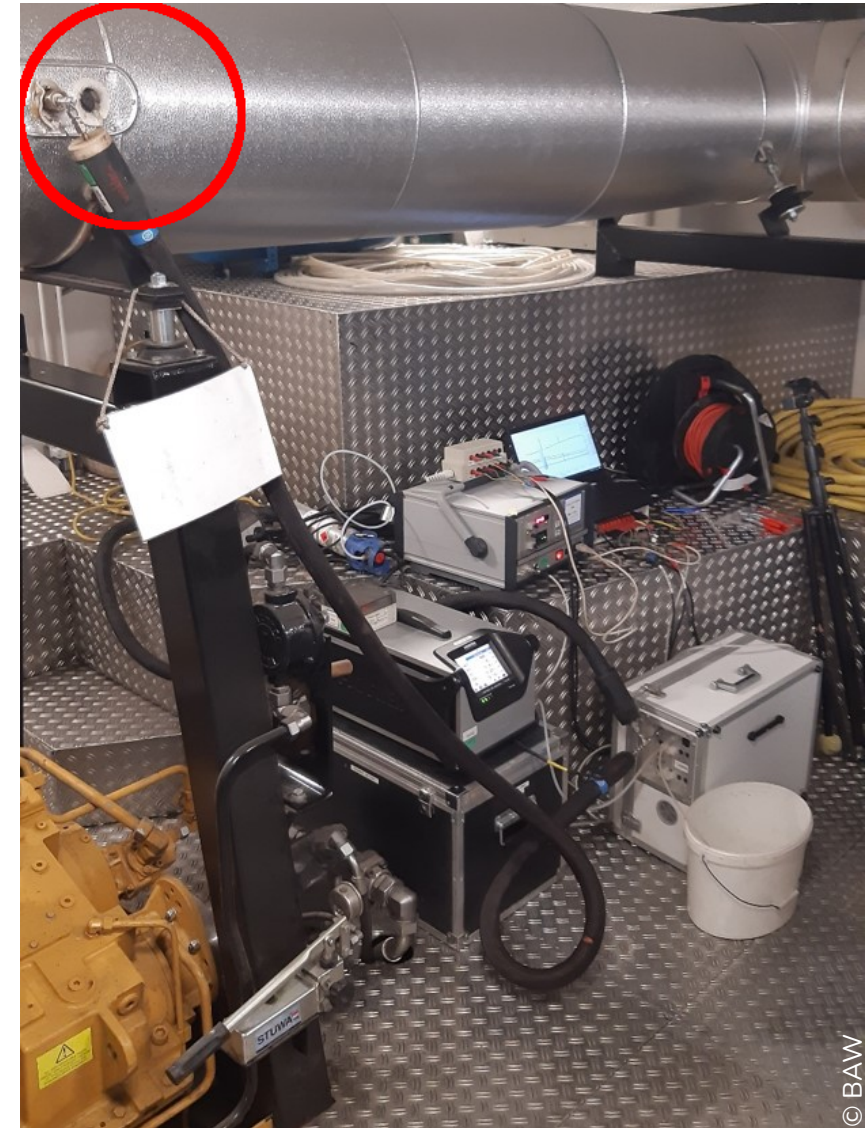
Measuring Equipment

- Measurement with multi-gas analyzer: CO₂, NO_x, CO, and HC.



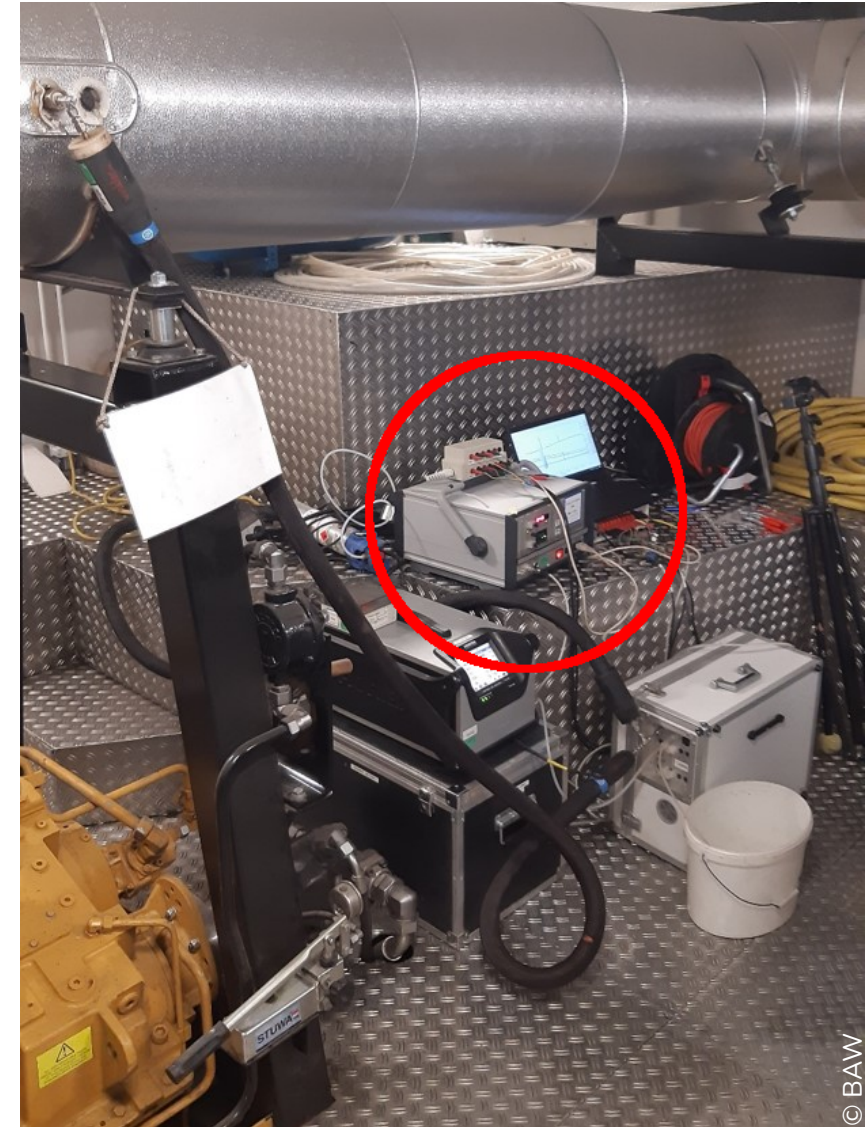
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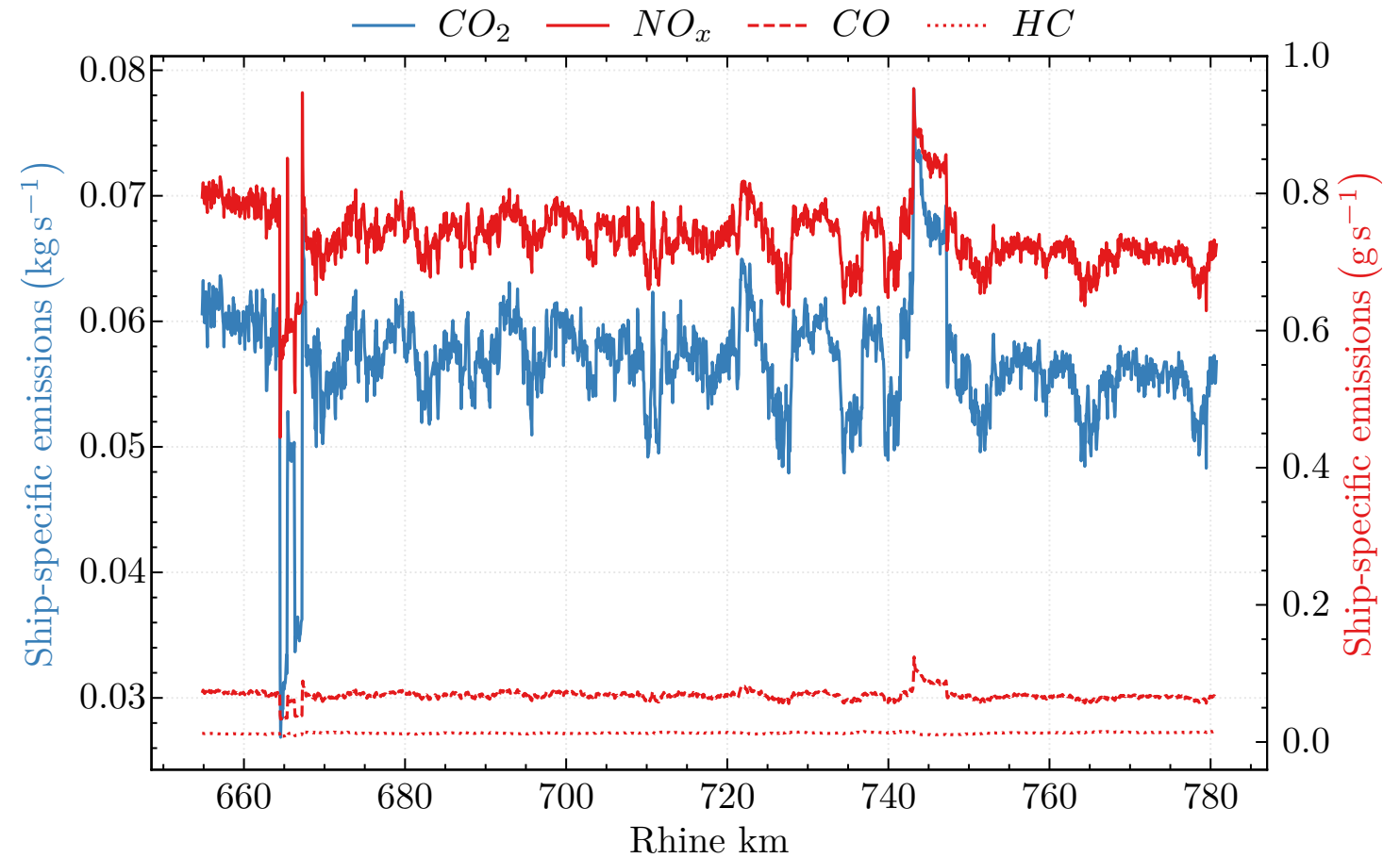
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- Sampling through a sampling port at the exhaust pipe.
- Measurement frequency: 1 Hz.



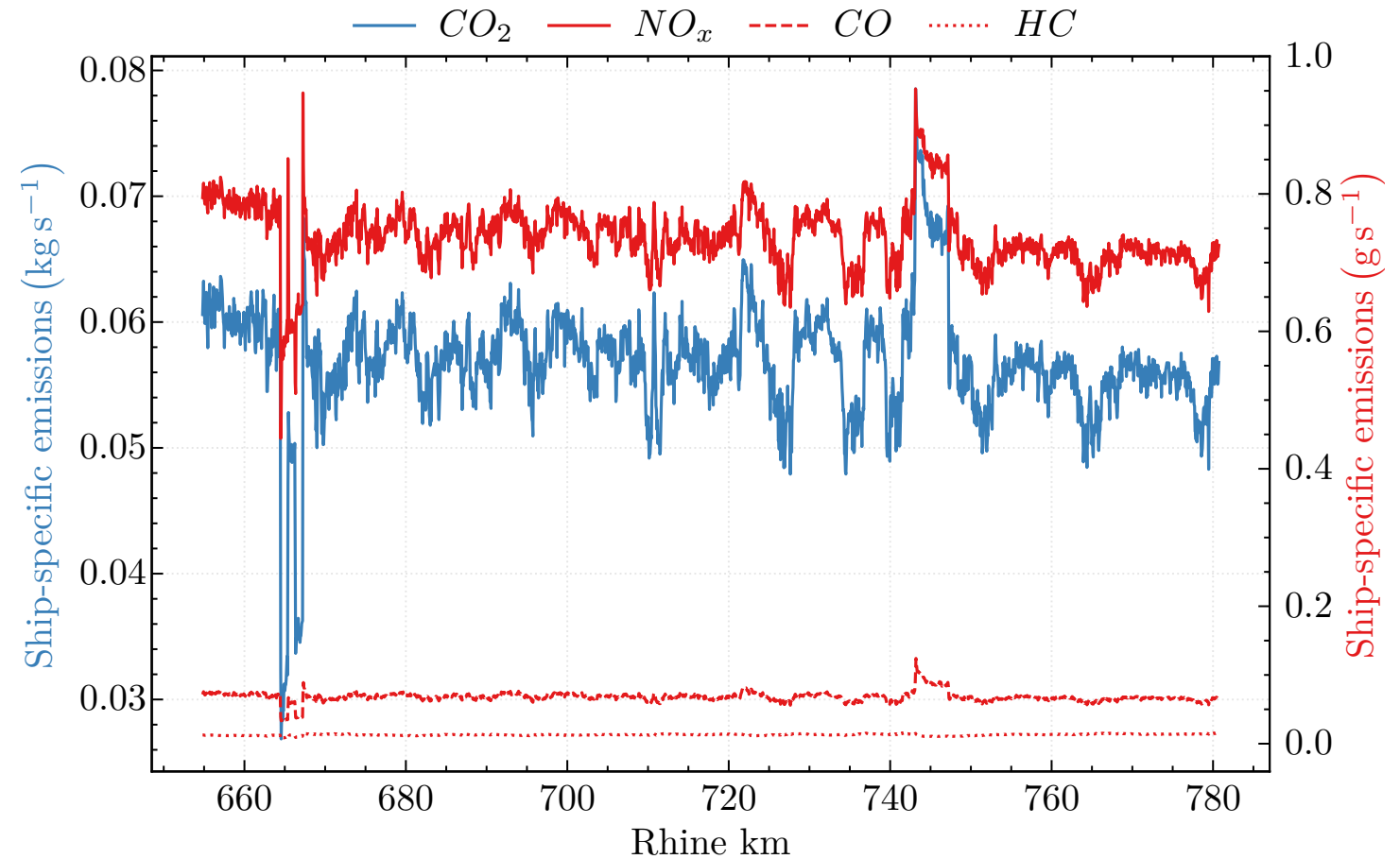
Measured Exhaust Gas Emissions

- Trends are consistent across all measured components.



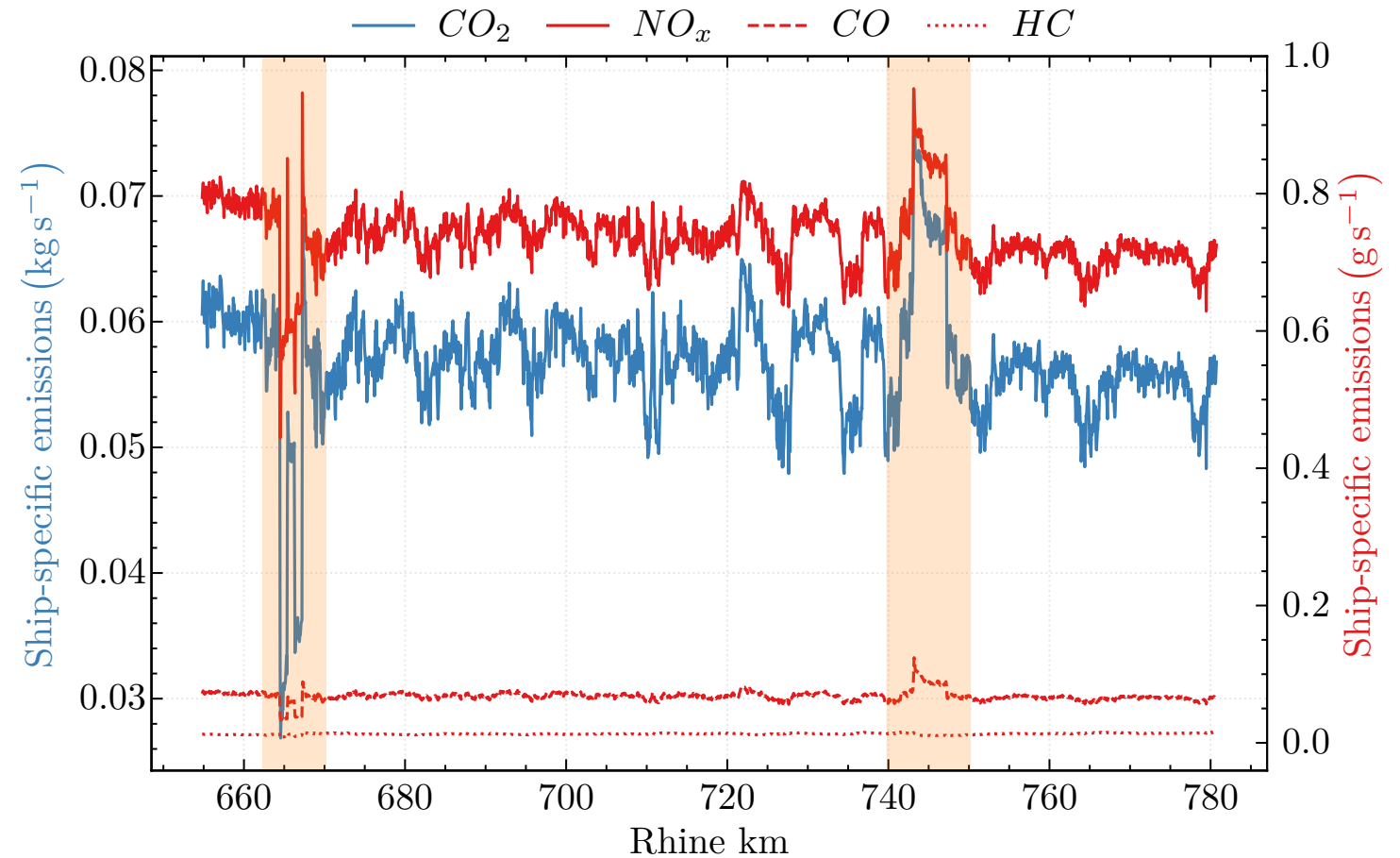
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- Trends are consistent across all measured components.
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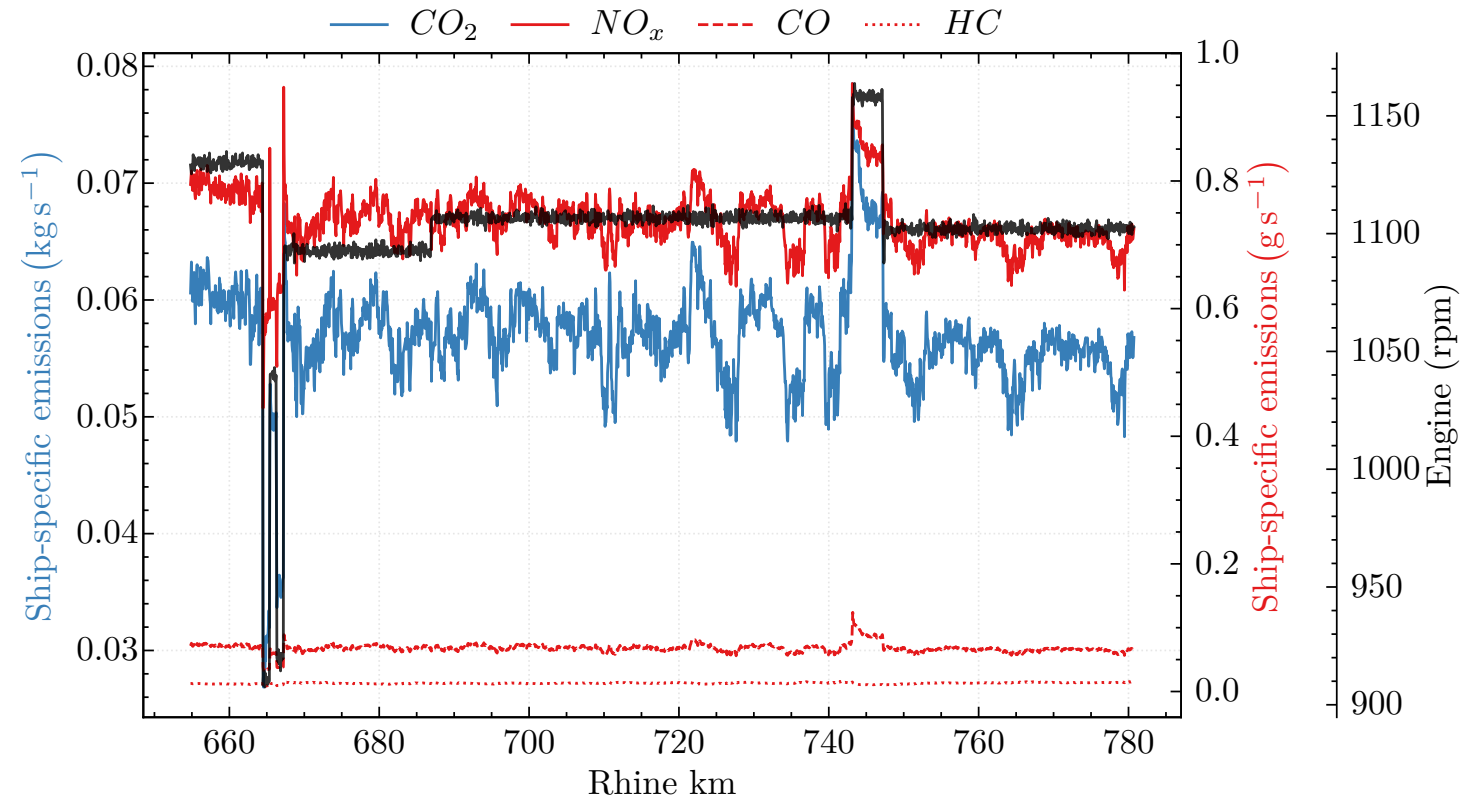
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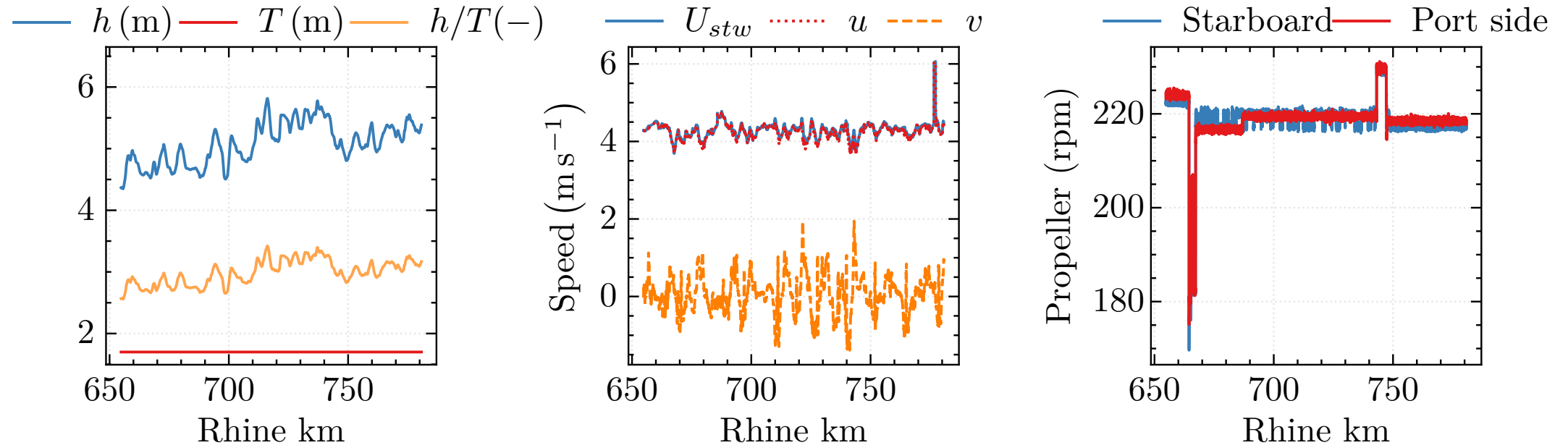


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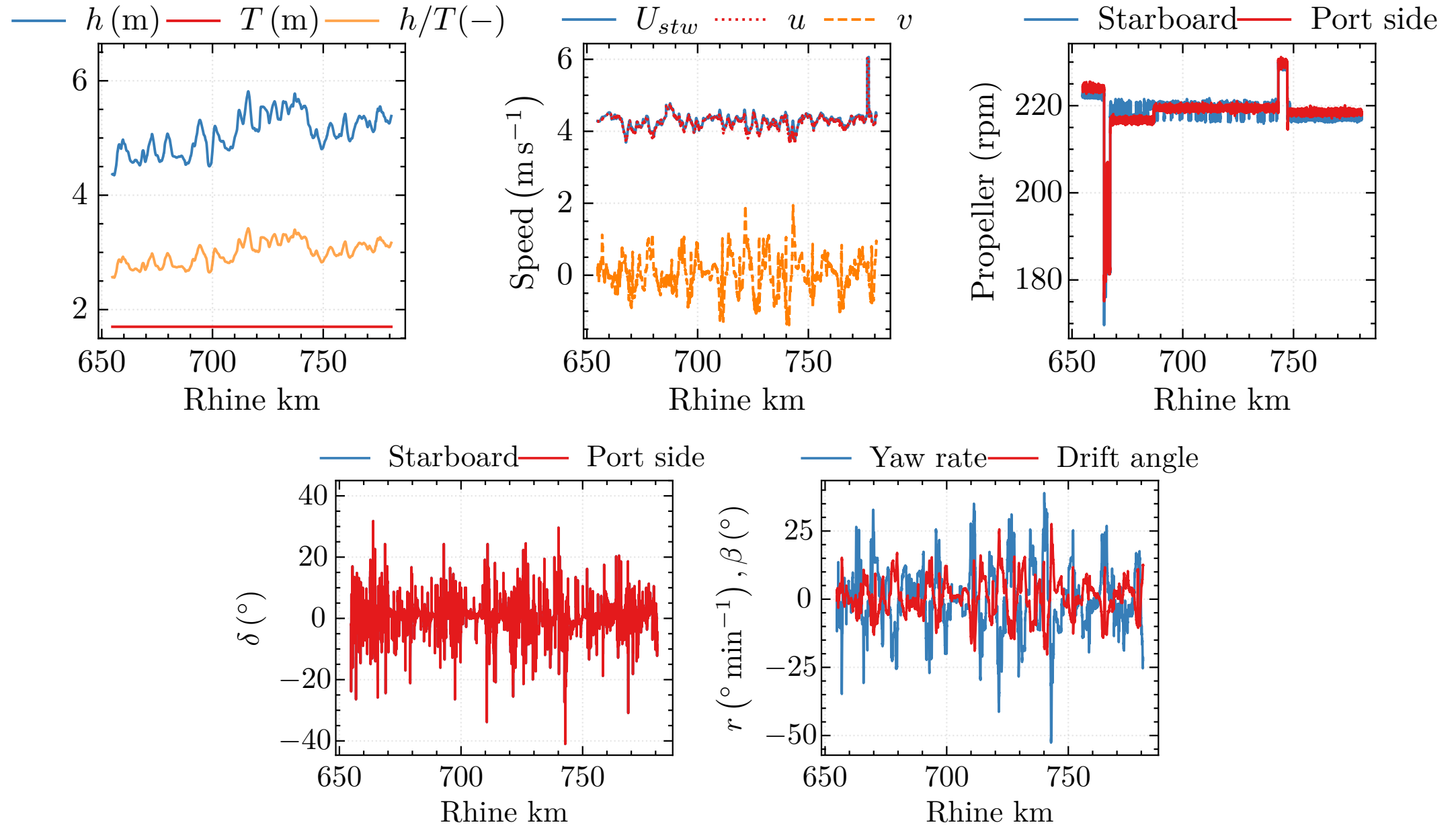
- Trends are consistent across all measured components.
- Magnitudes differ due to varying units.
- Peaks correlate with engine load.



Operational Data



Operational Data



Matrix of numerical simulations in full scale for more than **2000** cases.

Ship Speed U (km h ⁻¹)	: 12, 15, 18
Propeller Revolution n (rpm)	: 215, 222.5, 230
Water Depth to Draft Ratios h/T (-)	: 2.5, 3.0, 3.5

Test Matrix

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Propulsion	0	0	0
Drift	-24:4:24	0	0
Rudder	0	-40:5:40	0
Rotating Arm	0	0	-40:5:40

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Drift + Rotating Arm	-24:4:24	0	-40:5:40
Rotating Arm + Rudder	0	-40:5:40	-40:5:40

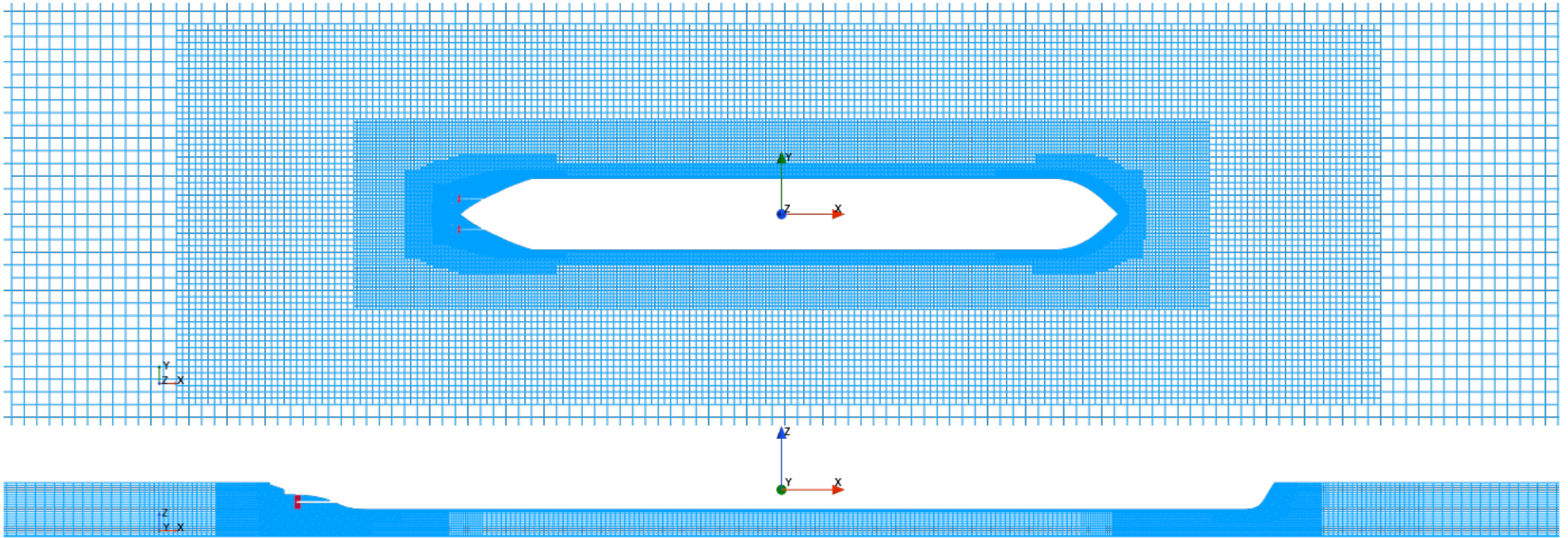
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Numerical Method

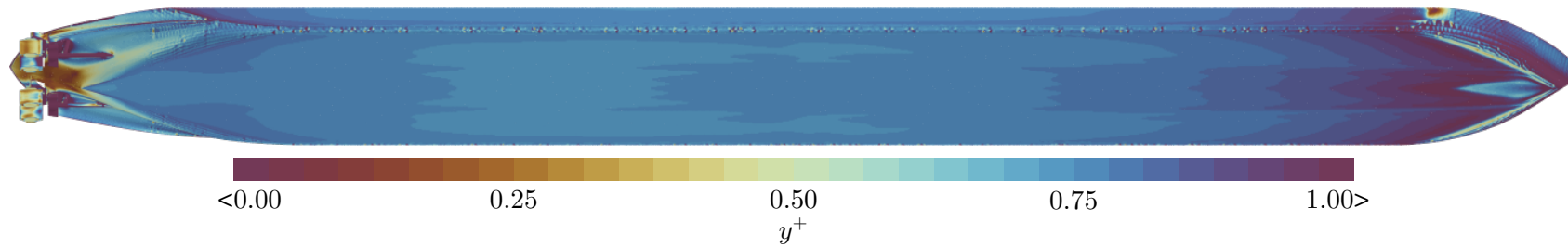
- Double-body with RANS and Reynolds stress model (RSM).



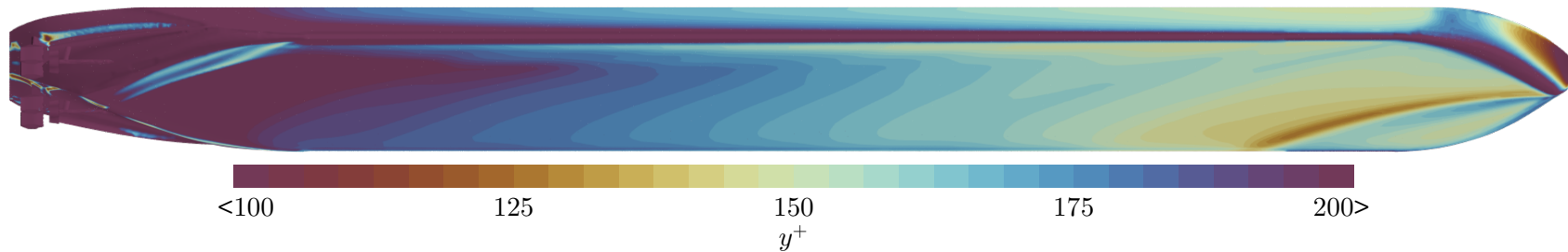
Full scale.

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- Model scale simulation with low $y^+ < 1$ and high $y^+ > 100$ in full scale.



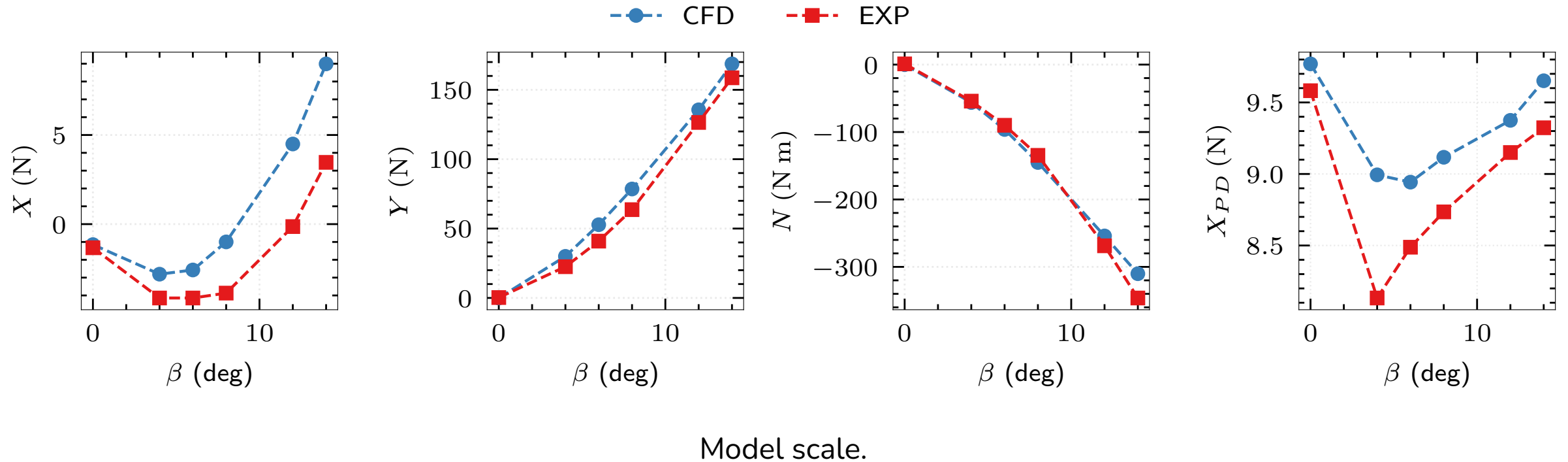
Model scale.



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Numerical Method

- Double-body with RANS and Reynolds stress model (RSM).
- Model scale simulation with low $y^+ < 1$ and high $y^+ > 100$ in full scale.
- Validation with experimental results in model scale.



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Emission Rate Calculation

- Emission rate CO₂:

$$ER_{CO_2} = P_B \cdot BSFC \cdot EF_{CO_2},$$

- Brake Specific Fuel Consumption [1]: $BSFC = 0.2 \text{ kg}_{\text{fuel}}/\text{kWh}$.
- CO₂ emission factor [3]: $EF_{CO_2} = 3.16 \text{ kg}_{CO_2}/\text{kg}_{\text{fuel}}$.

Power Prediction Models

- Engine brake power:

$$P_B = \frac{F}{\eta_D \eta_T} U_{stw},$$

- Propulsion efficiency [2]: $\eta_D = 0.5$.
- Transmission efficiency [4]: $\eta_T = 0.941$.

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- FaRAO Model (BAW):

$$F = f(U_{stw}, L_{PP}, B, T, C_B, h, W, B_i, r_C),$$

- Modular Maneuvering Model (BAW):

$$\begin{aligned} F &= F_H + \sum_i F_{P_i} + \sum_j F_{R_j}, \\ &= f(u, v, r, \dot{u}, \dot{v}, \dot{r}, n_P, \delta, h'), \end{aligned}$$

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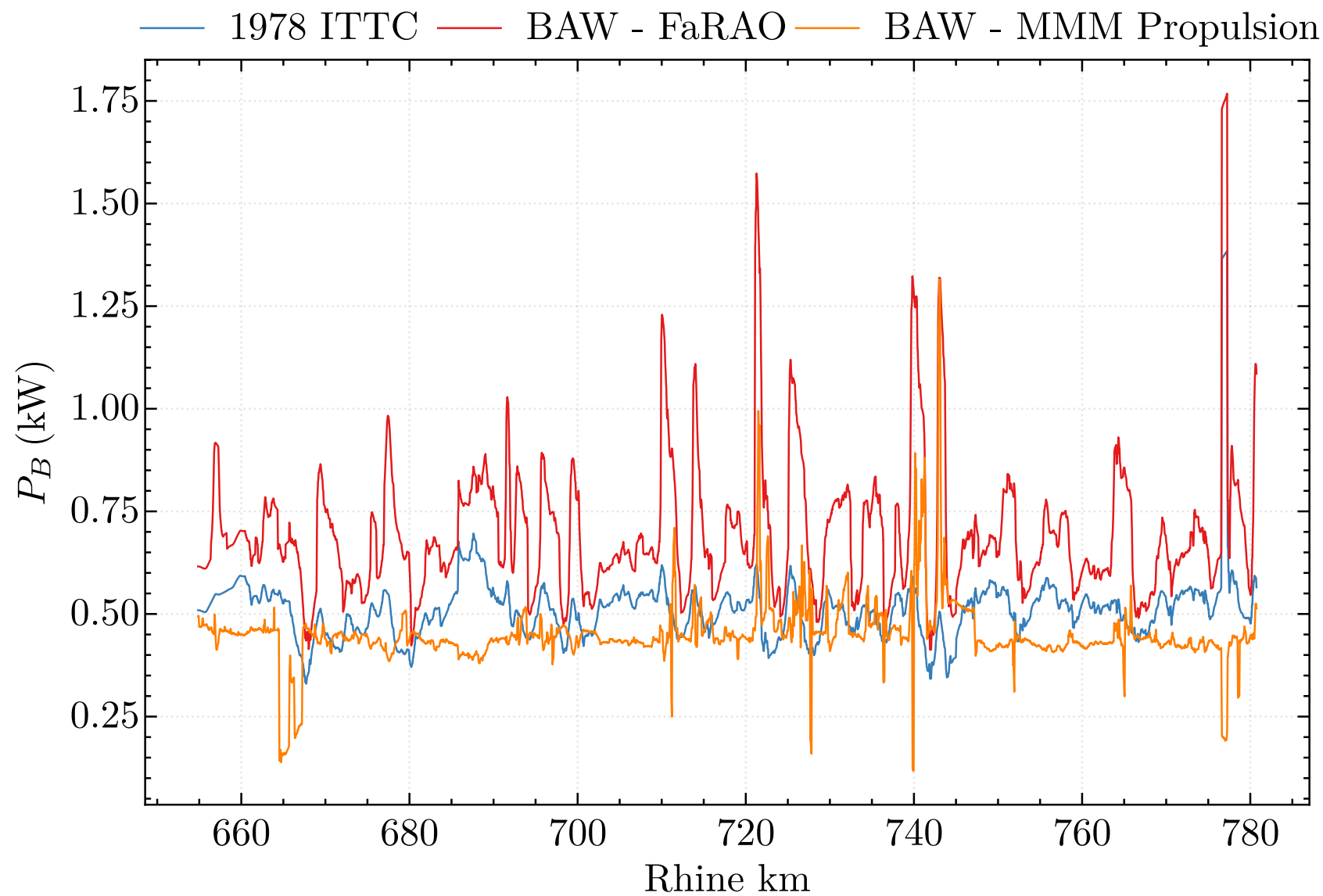
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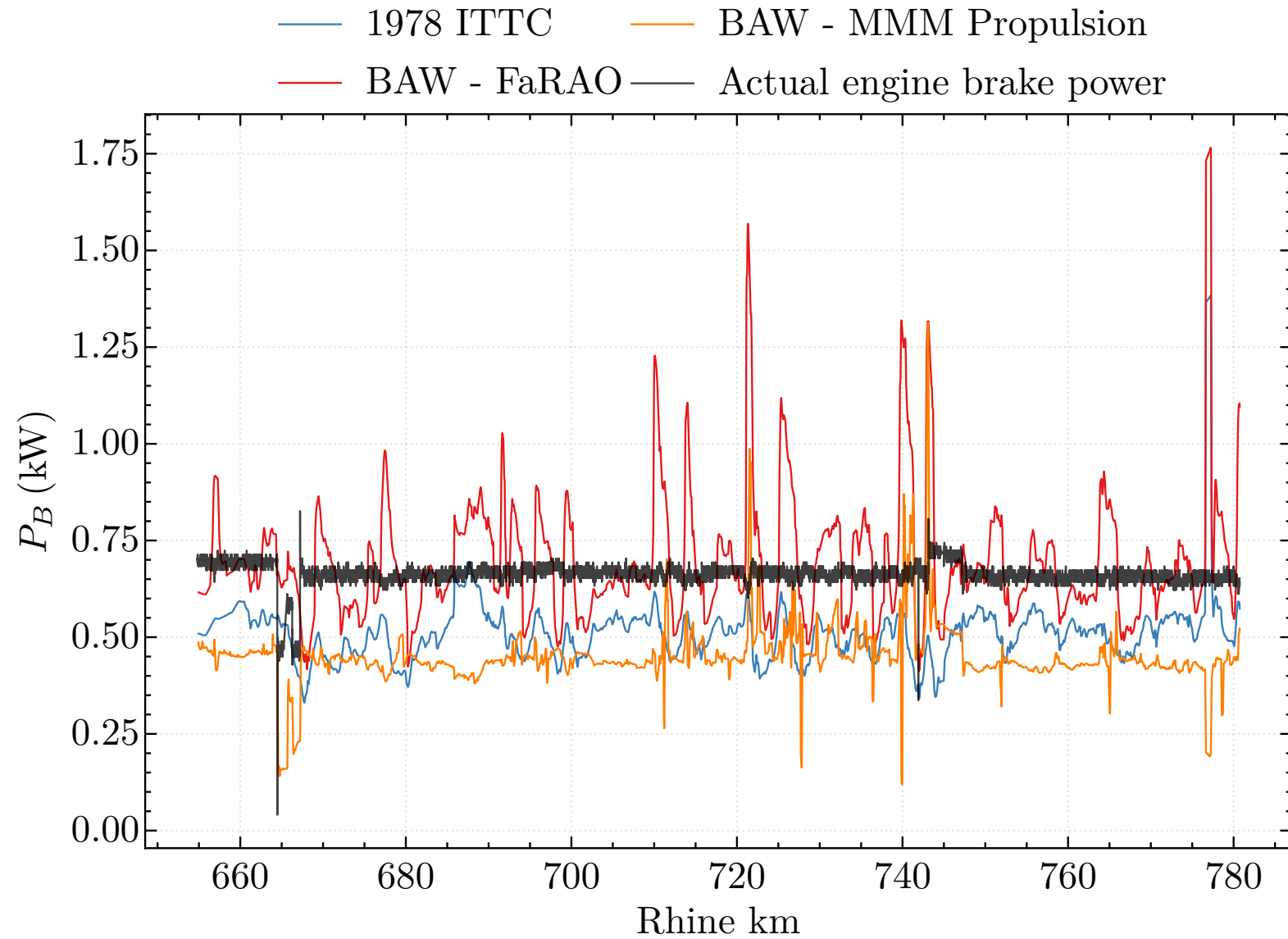
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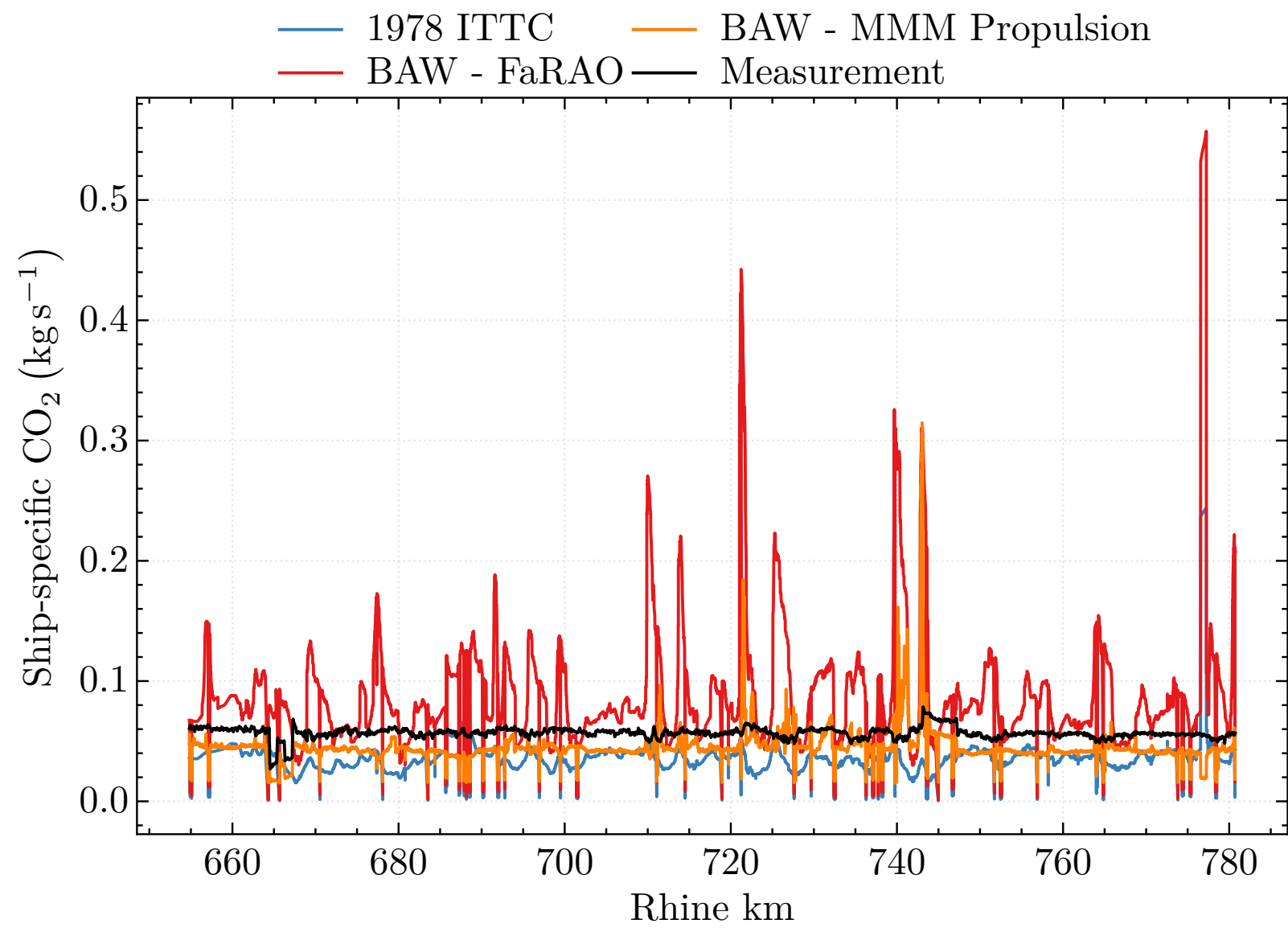
Modeling Engine Brake Power



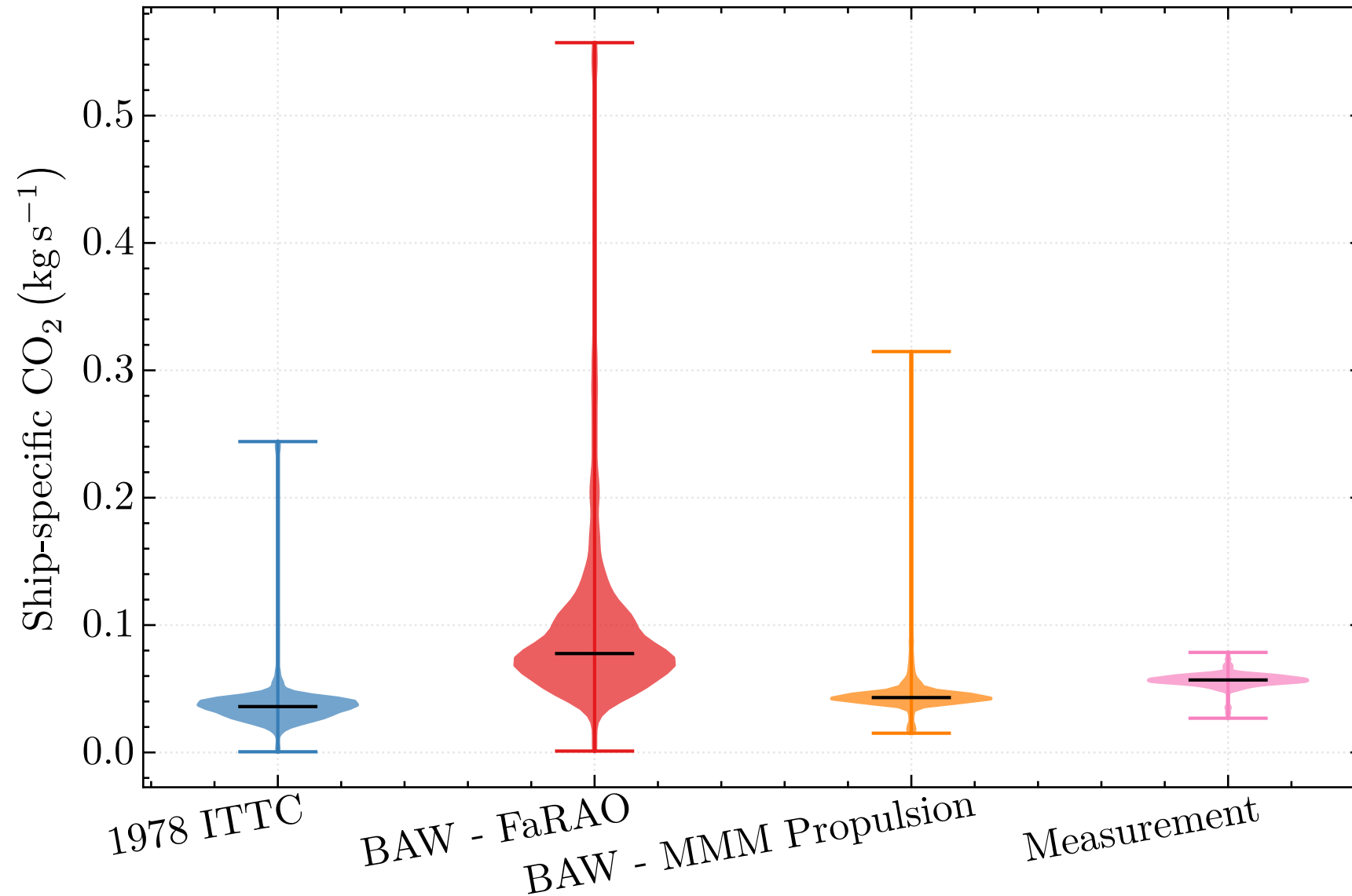
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Comparison of the Modeled and Measured Emissions



Distribution of the Modeled and Measured Emissions



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- Enhancement of model accuracy and reliability for improved prediction of ship-specific CO₂ emissions.
- Integration of real-time emission prediction in ship-handling simulators .

Thank you for your attention!

References I

- [1] Caterpillar Inc. *3512C – SS Marine Propulsion: Technical Specifications*. Tech. rep. LEHM0002-00. Caterpillar Inc., 2008. URL: https://zps-cdn.prod.dx.zndbx.cloud/3512_C_LEHM_0002_00_886666c3d3.pdf.
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