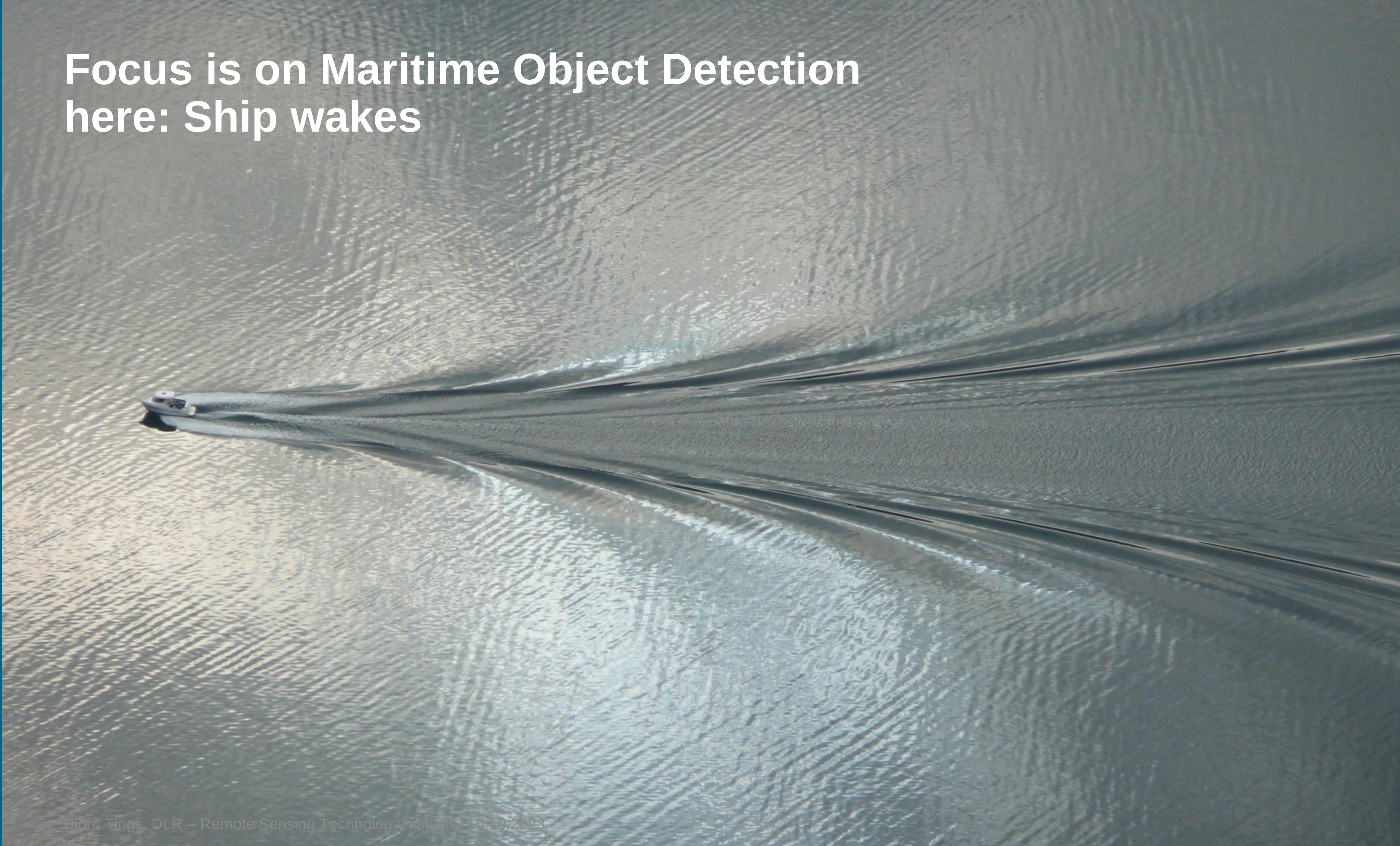
UNCERTAINTY ESTIMATION FOR DETECTABILITY MODELLING WITHOUT GROUND TRUTH

International Future Lab - AI4EO Symposium 2023

Björn Tings, DLR – Remote Sensing Technology Institute, 10.10.2023

Focus is on Maritime Object Detection here: Ship wakes

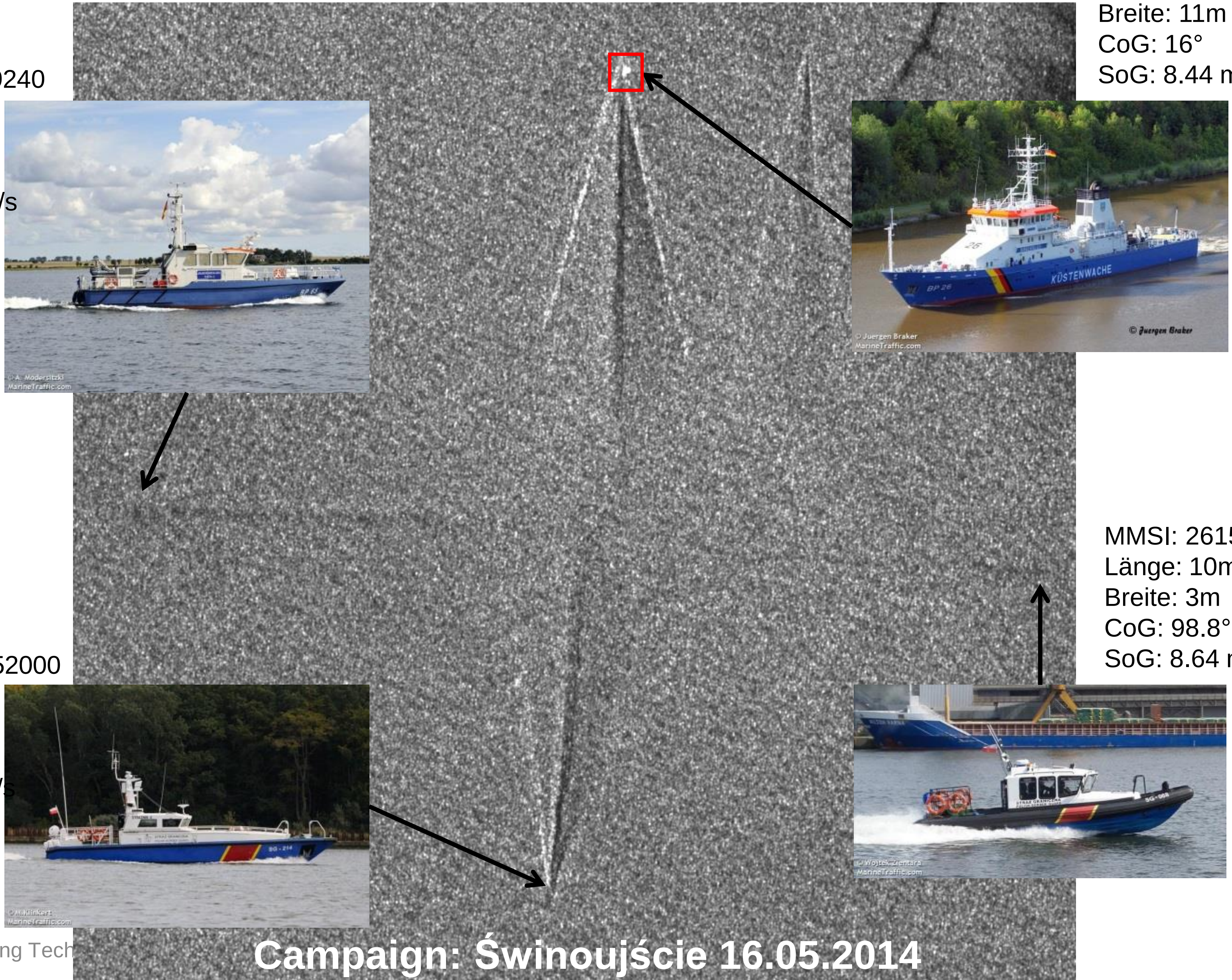


Edmont, "Boat sailing the Lyse fjord in Norway. Picture taken from the Preikestolen." CC BY-SA 3.0, Created: 14 April 2009

Detectability of wakes

MMSI: 211179240
Länge: 22m
Breite: 6m
CoG: 284.3°
SoG: 10.24 m/s

MMSI: 211404810
Länge: 66m
Breite: 11m
CoG: 16°
SoG: 8.44 m/s

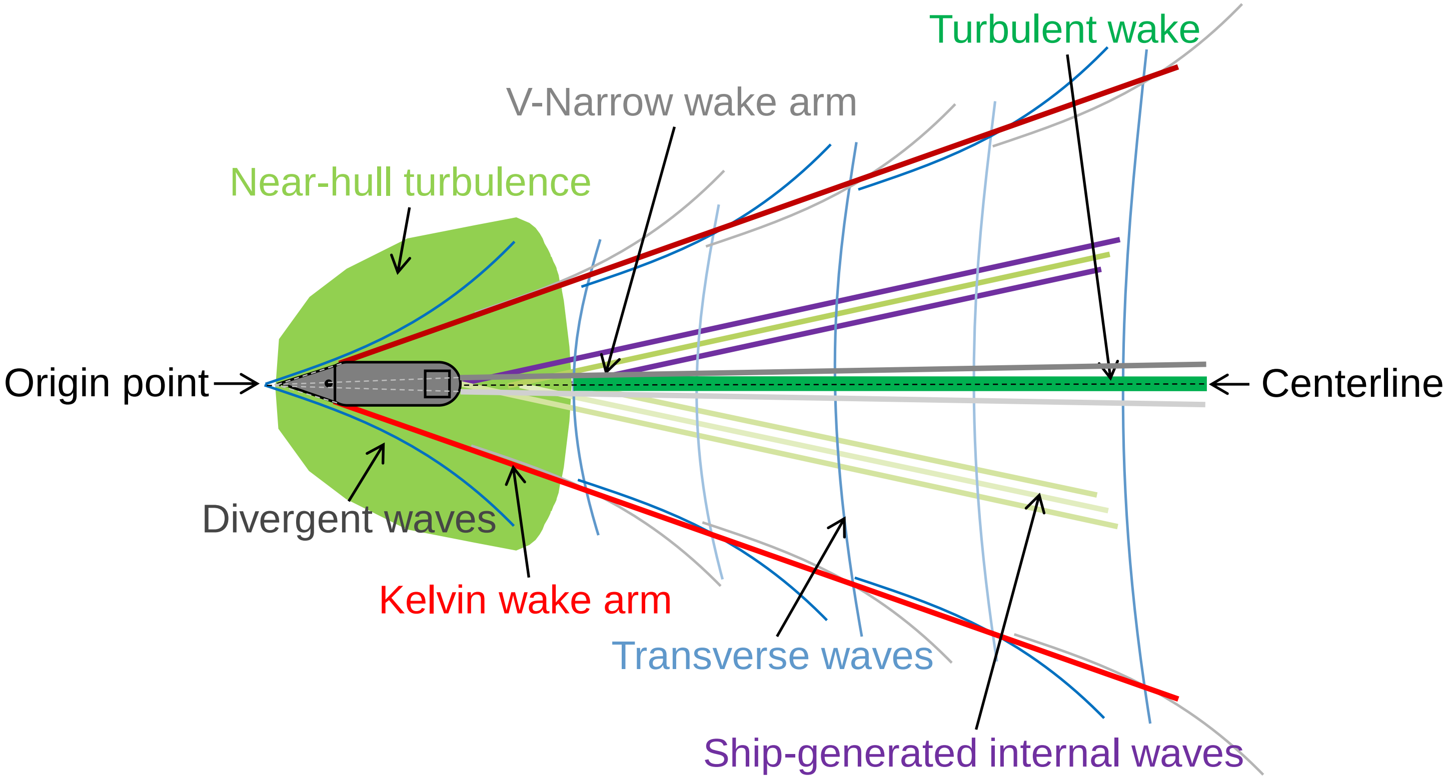


MMSI: 261352000
Länge: 16m
Breite: 4m
CoG: 194.8°
SoG: 9.04 m/s

MMSI: 261520000
Länge: 10m
Breite: 3m
CoG: 98.8°
SoG: 8.64 m/s

Campaign: Świnoujście 16.05.2014

Wake components in SAR



Wake detectability modelling
Wake component dataset

- ~3000 TerraSAR-X wake samples in the dataset
- Vessel information retrieved from AIS
- Wake components manually retraced

- Proportion of main wake components in the used dataset:

Wake component	Proportion (rounded to integer)
Turbulence	59%
Turbulent wake	61%
Kelvin wake arm	21%
V-narrow wake arm	27%

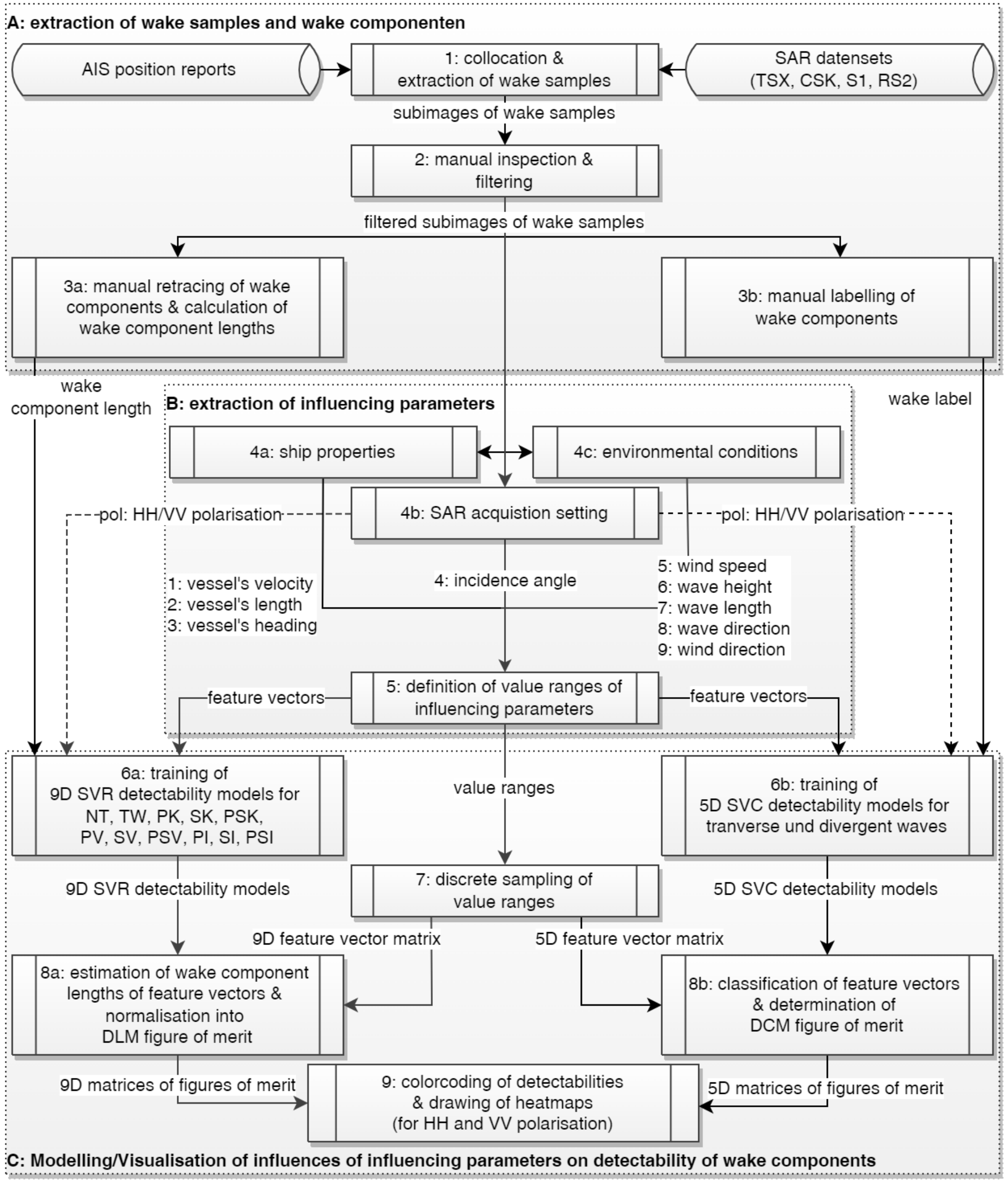
Wake detectability modelling
Wake component dataset

- Nine Influencing parameters affecting the detectability:

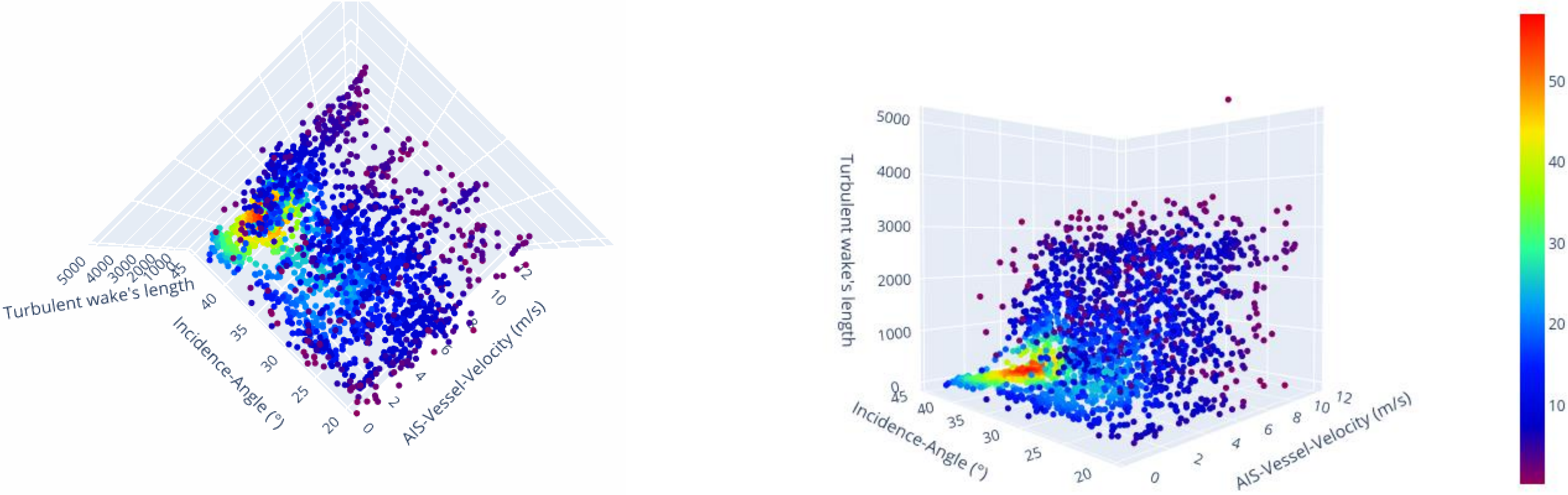
Symbol with index x_i	Influencing Parameter Name	Description
x_1	AIS-Vessel-Velocity	Velocity of the vessel derived from AIS messages interpolated to the image acquisition time
x_2	SAR-Wind-Speed	Wind speed estimated from the SAR background around the vessel using the CMOD-5h or XMOD-2 geophysical model function
x_3	Incidence-Angle	Incidence angle of the radar cropped full performance value range
x_4	AIS-Length	Length of the corresponding vessel based on AIS information
x_5	AIS-CoG	The course over ground based on AIS information relative to the radar looking direction (0° means parallel to range and 90° mean parallel to Azimuth).
x_6	SAR-Significant-Wave-Height	Significant wave height estimated from the SAR background around the vessel using the SAR-SeaStaR algorithm
x_7	SAR-Significant-Wave-Length	Wave length estimated from the SAR background around the vessel using the SAR-SeaStaR algorithm
x_8	AIS-CoG-SAR-Wave-Direction	Absolute angular difference between AIS-CoG and wave direction estimated from the SAR background around the vessel using the SAR-SeaStaR algorithm
x_9	AIS-CoG-WRF-Wind-Direction	Absolute angular difference between AIS-CoG and wind direction estimated by the Weather Research and Forecasting Model (WRF) nearby the vessel.

Wake detectability modelling
Procedure for analysis of detectability

- Localizing moving vessels by AIS data collocated with SAR images
- Filtering of SAR-artifacts not related to ship movements
- Manual inspection
- Extracting influencing parameters
- **Modelling of detectability**
- **<u>Estimation of uncertainty</u>**
- Plotting and Interpretation



Wake detectability modelling
Visualization of feature space



Wake detectability modelling
Modelling the wake component detectability

- Wake component length l_w is used as indicator for wake component detectability
- Training a Support Vector Regression model f_w for mapping wake component length l_w to the influencing parameters x_i:

$l_w = f_w(X^{9D})$, with $X^{9D} = \{x_1; x_2; x_3; x_4; x_5; x_6; x_7; x_8; x_9\}$ and w denotes wake component

- Detectable Length Metric (DLM, figure of merit for detectability) is calculated by normalizing l_w linearly between a minimum and maximum boundary:

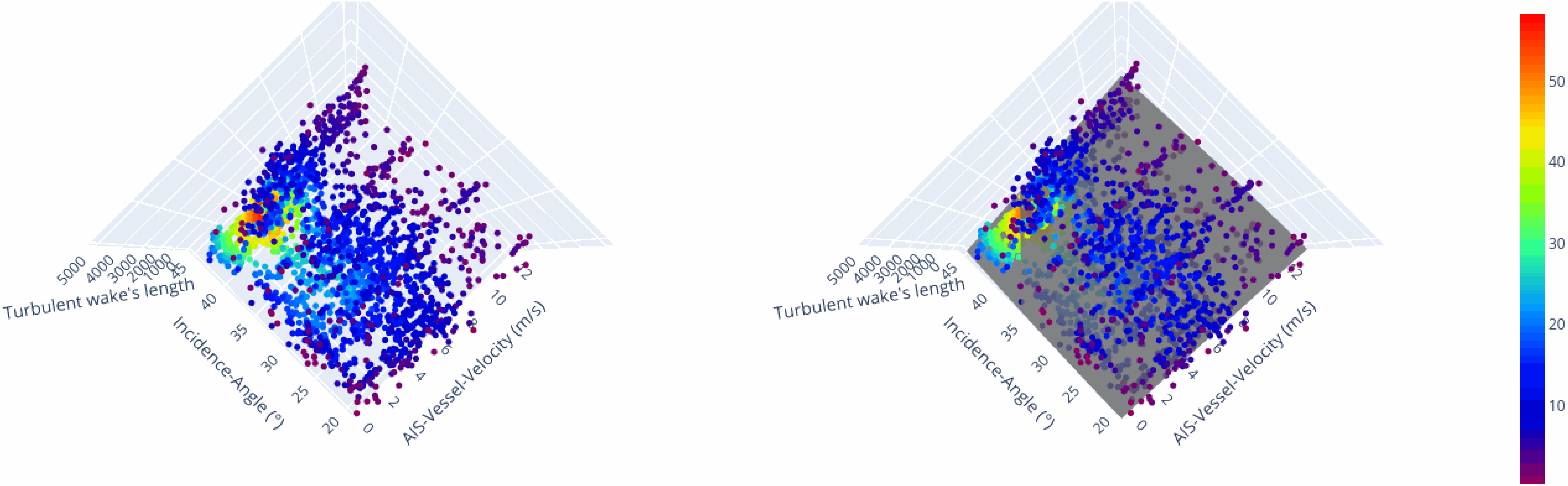
$$DLM_w = g_w(l_w) = \frac{l_w - l_w^{min}}{|l_w^{max} - l_w^{min}|},$$

hyperparameter settings are:

hyperparameter name	value
Kernel type	polynomial
Kernel degree d	2
error tolerance ε	0,001
error weighting C	1,0
gradient γ	0,0
offset β	0

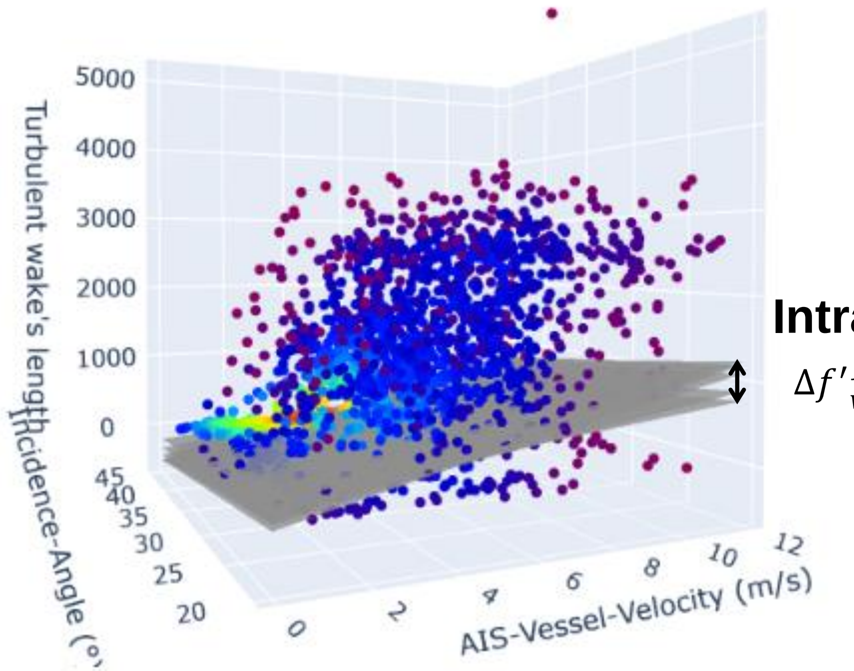
Wake detectability modelling
Visualization of feature space with detectability model

- Gray hyperplane represents the detectability model



Wake detectability model's uncertainty
Visualization of uncertainty estimation method

- Feature space with five hyperplanes trained on five subsets of original training dataset
- Differences between each hyperplane to each other hyperplane are sampled



Intra-Model-Differences

$$\Delta f'^{j,o}_{w} = f'^{j}_{w} - f'^{o}_{w}$$

Wake detectability model's uncertainty
Uncertainty estimation

- Distances between models are used for uncertainty estimation
- Mathematical operation "square", "mean" and "root" are applied in that sequence on Intra-Model-Differences:

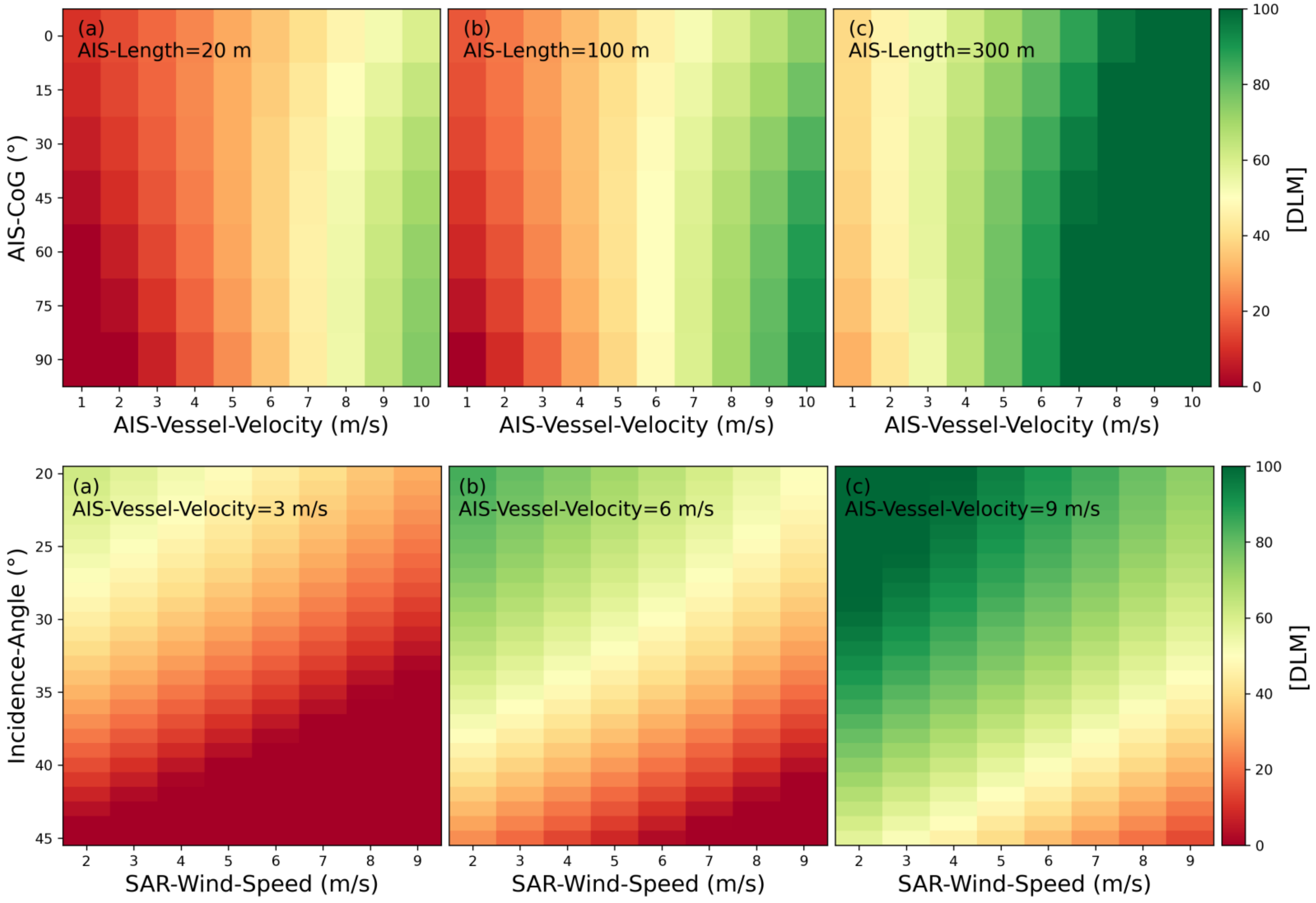
$$\mathrm{RMSE}_w^{j,o} = \sqrt{\frac{1}{\prod_{i=1}^{5}|D_i|}\sum_{x_i \in D_i, i,\ldots,5}\left(\Delta f_w^{j,o}(X^{5D})\right)^2}, \forall j \in \{j \in \mathbb{N} | 1 \leq j \leq n\}, \forall o \in \{o \in \mathbb{N} | 1 \leq o \leq n \wedge o \neq j\}$$

- Individual $\mathrm{RMSE}_w^{j,o}$ for two subset-based models are averaged

$$\overline{RMSE_w} = \frac{1}{20}\sum_{j=1}^{5}\sum_{o=1, j\neq o}^{5, j\neq o}\mathrm{RMSE}_w^{j,o}$$

- $\overline{RMSE_w}$ ist estimator for total uncertainty of the detectability model

Wake detectability modelling
View into 9D non-linear model for turbulent wakes



Wake detectability model's uncertainty
Significance test of detectability characteristics

- Variation in detectability in dependency to one influencing parameter c for a static setting of all other influencing parameters o:

$$\Delta DLM_w = \left| \max_{\forall x_c \in I_c, \exists x_o \in I_o} g_w\big(f_w(x_c, X_{o \neq c})\big) - \min_{x_c \in I_c} g_w\big(f_w(x_c, X_{o \neq c})\big) \right|, \exists x_o \in I_o$$

- Variation is significant if:

$$\overline{RMSE_w} < \Delta DLM_w$$

Wake detectability model's uncertainty
Application of model's uncertainty to model's analysis

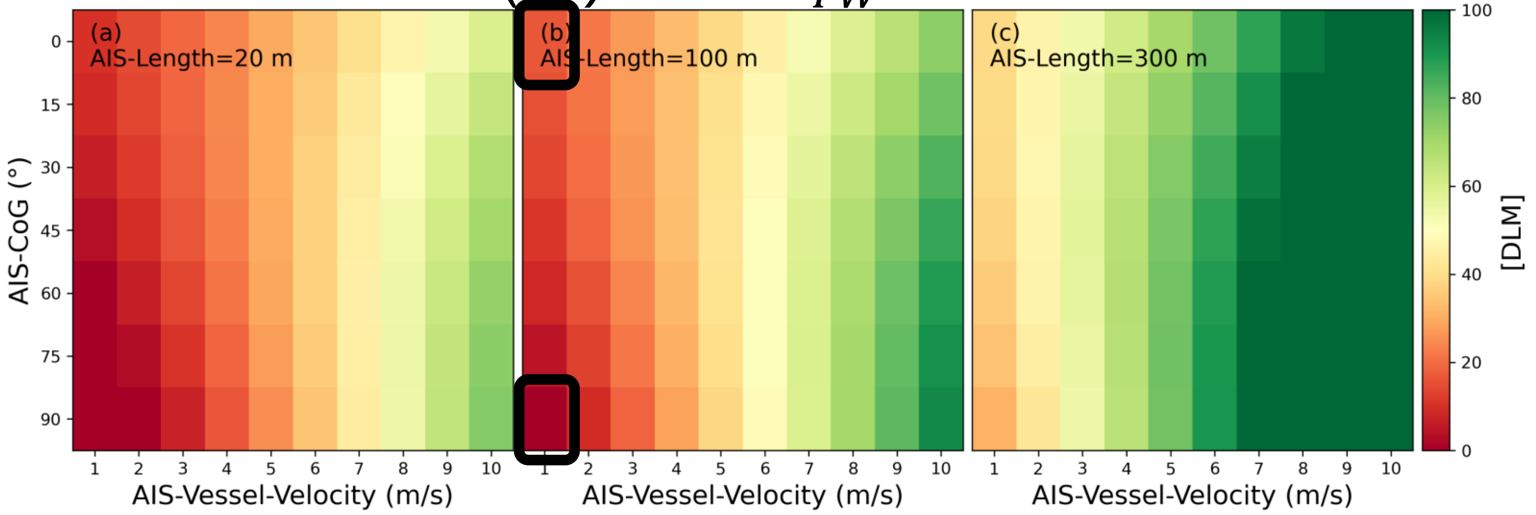
Total model's uncertainty for turbulent wakes (tw): $\overline{RMSE_{TW}} = 0.16$

$g_{tw}(363\,m) = 0.09$

$g_{tw}(54\,m) = 0.00$

$\Delta DLM_{\mathrm{tw}} = 0.09$

$0.16 < 0.09$ ✗

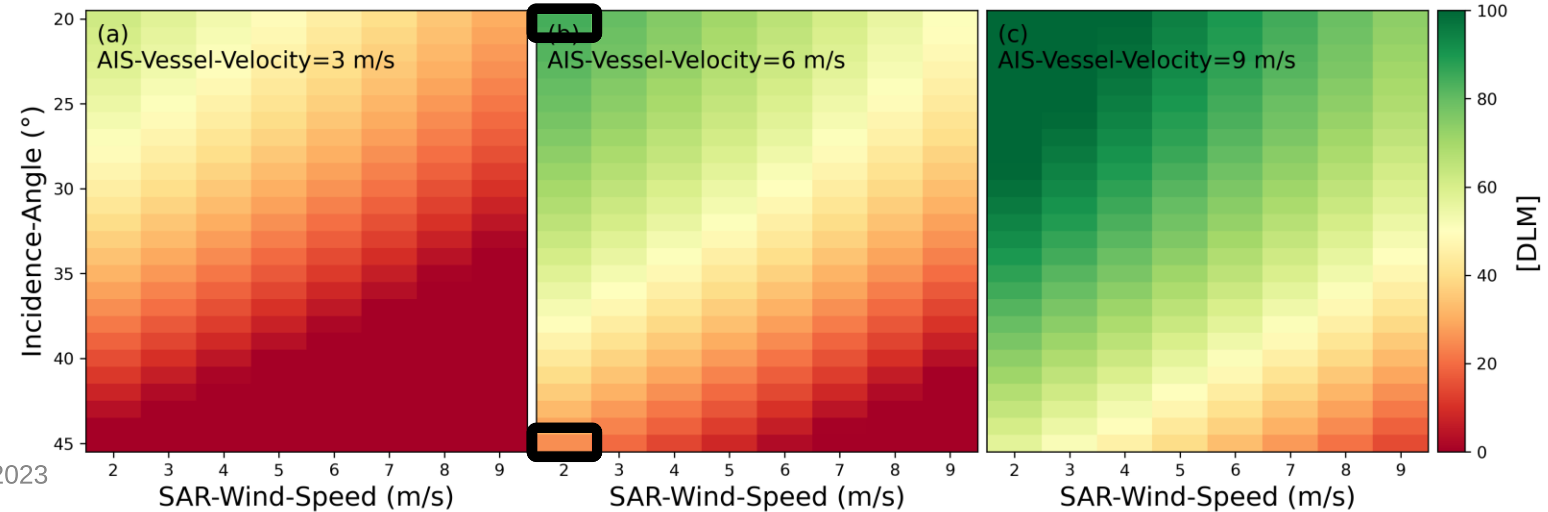


$g_{tw}(1505\,m) = 0.75$

$g_{tw}(588\,m) = 0.22$

$\Delta DLM_{\mathrm{tw}} = 0.53$

$0.16 < 0.53$ ✓



Summary & Conclusion

- Method is based on assumption:
  "Machine Learning models robustly trained on dataset with **infinite** size and on derived data subset are identical"
- Differences between multiple models independently trained on data subsets derived from original dataset with **finite** size, are used for estimation of uncertainty of model trained on original dataset

- Characteristics describing influences of physical parameters on detectability of objects can be derived from detectability models

➢ Estimators of uncertainty can be used to test significance of characteristics

References

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- B. Tings, “Non-Linear Modeling of Detectability of Ship Wake Components in Dependency to Influencing Parameters Using Spaceborne X-Band SAR”, *Remote Sensing*, 2021, 165
- B. Tings, A. Pleskachevsky, S. Wiehle, “Comparison of detectability of ship wake components between C-Band and X-Band synthetic aperture radar sensors operating under different slant ranges”, *ISPRS Journal of Photogrammetry and Remote Sensing*, 2023, 306-324

About

Subject: **Uncertainty Estimation for Detectability Modelling without Ground Truth**
AI4EO Symposium 2023

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Thank you!

Questions? Critics?