NO2 ship-plume segmentation with supervised learning on TROPOMI/S5P satellite data

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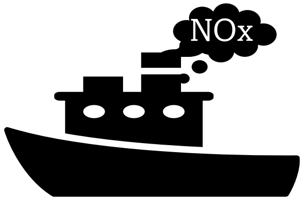
Motivation

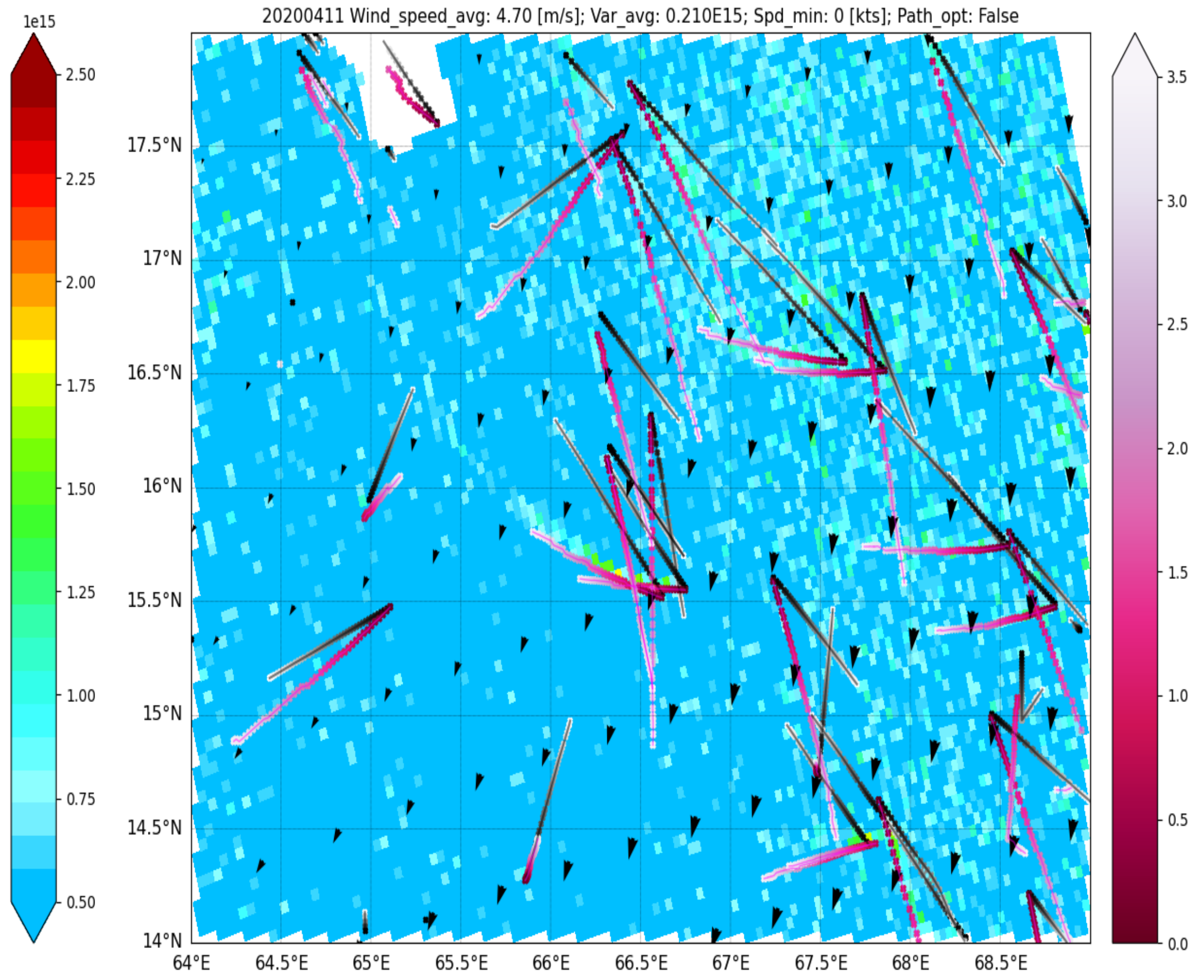


- Shipping industry - one of the biggest (15-35% worldwide) NOx/SOx emitters
- International Maritime Organization (IMO) tightens the restrictions regarding NOx/SOx presence in ships' fuel
- Lack of possibilities to perform a fuel quality monitoring above the open sea

Idea: *Application of TROPOMI measurements for automatic estimation of the amount of NO2 produced by individual ships*

Data example:

- **Background – S5P-TROPOMI** NO2 tropospheric column;
- **Black lines** – original ships' traces from **AIS** data;
- **Magenta lines** – ships' traces shifted according to the wind speed/direction;
- **Colour intensity** decreases with the time passed before the TROPOMI overpass (scale in hours);
- **Black arrows** – wind direction;



Data pre-processing

a) **Ship Plume Image** – Topomi NO2 *VCD_trop* around the ship

b) **Image Enhancement** – local Moran's *I*

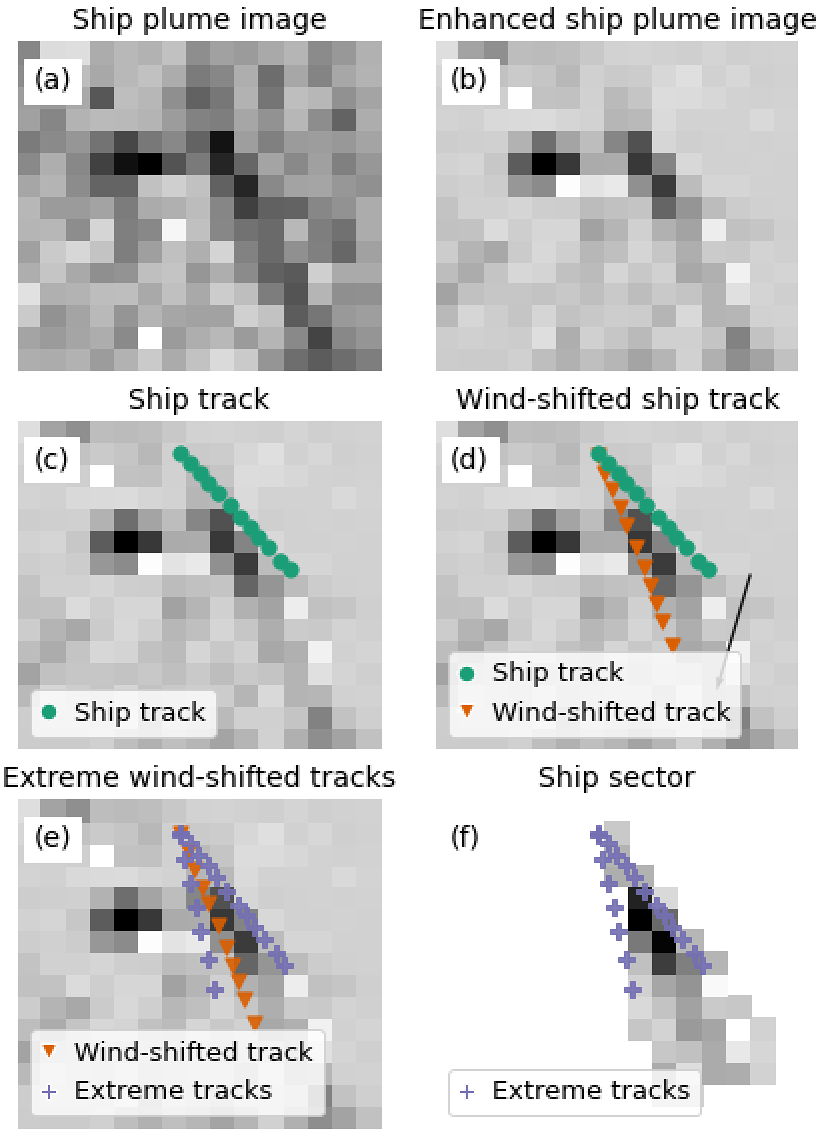
$$I_i = \frac{x_i - \bar{x}}{s^2} \sum_{j=1, j \neq i}^{n} w_{ij} (x_j - \bar{x})$$

c) **Ship Track** based on AIS data

d) **Shifted Ship Track** in accordance to wind speed/direction

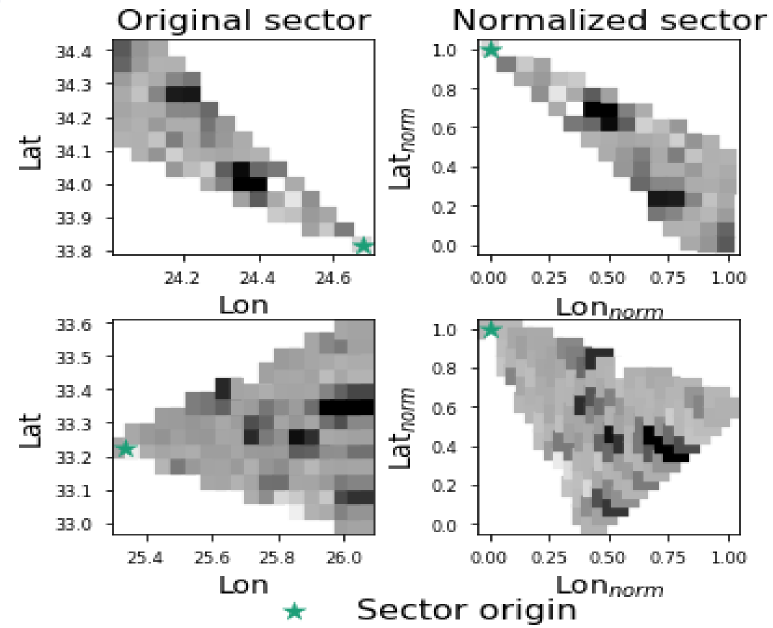
e) **Extreme Ship Tracks** – based on assumed wind uncertainty

f) **Ship Sector** – the ships' Region of Interest. We assume that the plume of analyzed ship is located within **Ship Sector.**

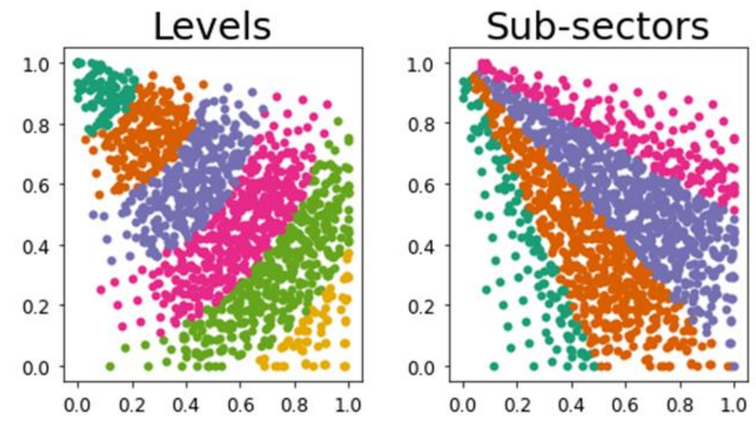


Sector standarization

Sector rotation
standardization of the position of the ship's plume with respect to the position of the ship



Sub- regions
the division allows to characterize each pixel within the normalized sector with two values: ***Level*** and ***Sub-sector***



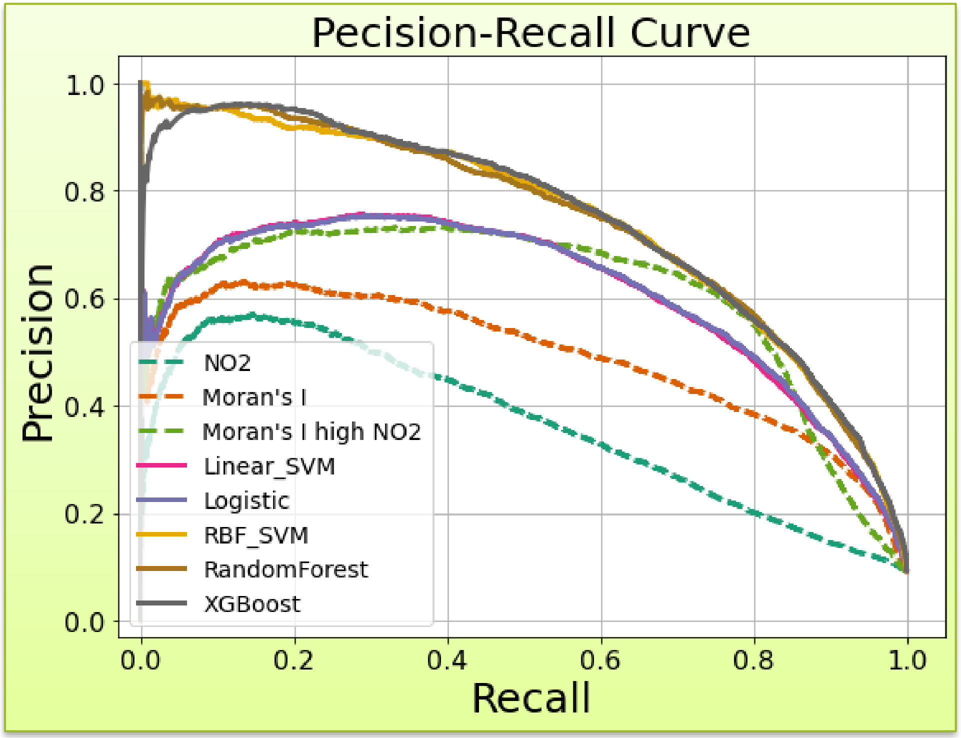
Experiment

- **Studied Area:** Mediterranean Sea [lon: 19.5 – 29.5; lat: 31.3 – 34.2]
- **Studied Period:** 04.2019 – 12.2019
- **Dataset:** 754 images manually labeled pixel-wise
- **Feature set:** 17 features including:
  - Pixel position in terms of Levels and Sub-sectors
  - Pixel intensity
  - Wind and ship related features
- **Models:** 5 linear and non-linear supervised classifiers
- **Benchmarks:** pixel intensity based thresholding methods (NO_2 based or Moran's I based)

Data Example

Results

	Model	Average Precision
Benchmarks	NO2	0.375±0.062
	Moran's I	0.493±0.063
	Moran's I on high NO2	0.607±0.056
Linear	Linear SVM	0.609±0.063
	Logistic	0.610±0.064
Non-linear	RBF SVM	0.742±0.031
	Random Forest	0.743±0.030
	XGBoost	**0.745±0.030**



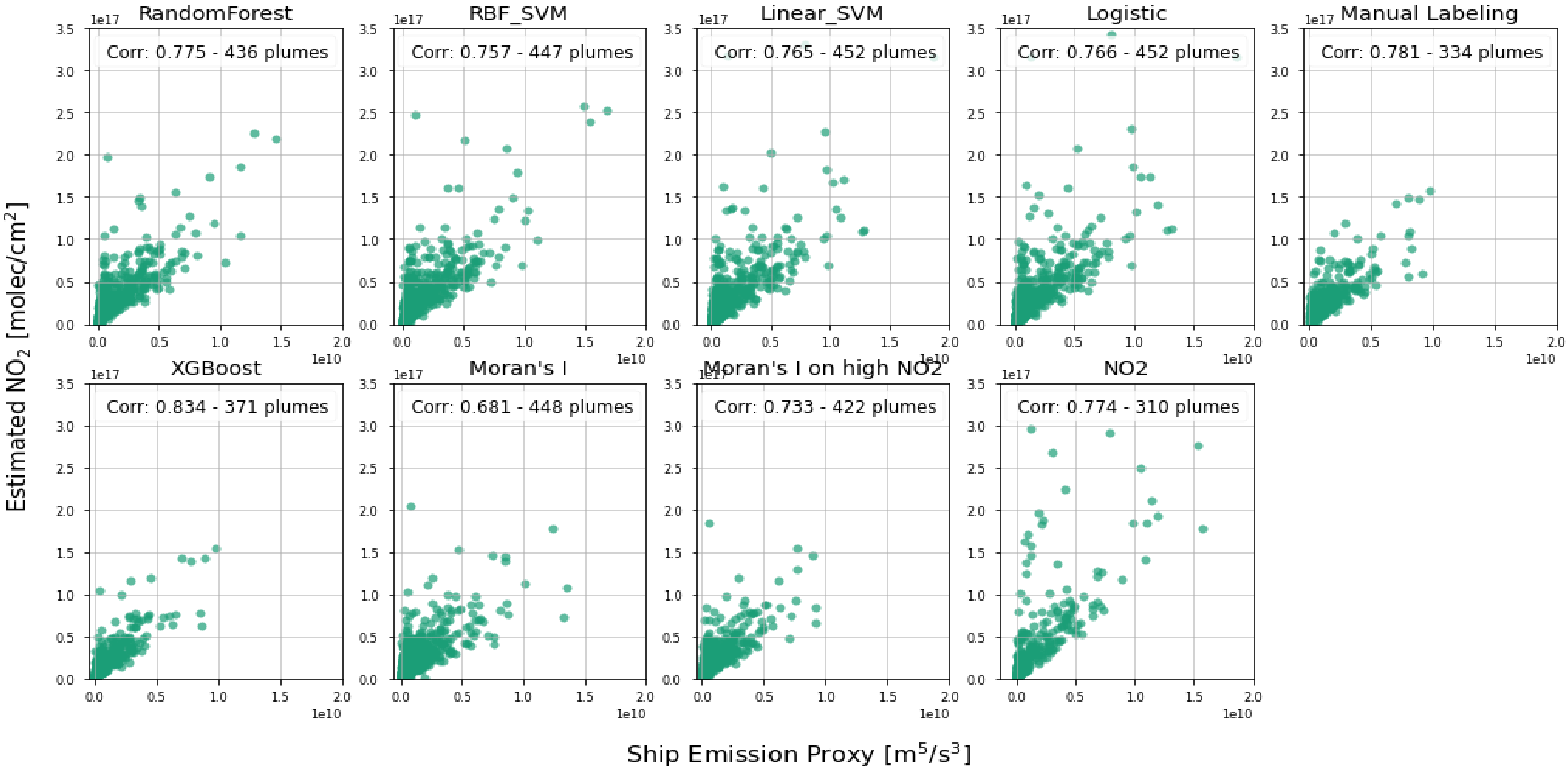
Conclusions

- All models outperform the benchmarks
- Non-linear models allow to achieve very high precision with acceptable level of recall

Validation of NO2 estimation

Ship emission proxy Es *allows to estimate the expected amount of produced NOx emission for a ship of a certain size and speed*

$$E_s = L_s^2 \cdot U_s^3$$



Thank you for attention!

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Read more about the study

Pre-print on arXiv

https://arxiv.org/abs/2203.06993

Full Results Supplement

$$\textbf{Precision} = \frac{True\ Positive}{True\ Positive + False\ Positive}$$

$$\textbf{Recall} = \frac{True\ Positive}{True\ Positive + False\ Negative}$$

$$\textbf{F1} = \frac{Precision * Recall}{Precision + Recall}$$

Average Precision (AP) – area under Precision-Recall curve

Model	Precision	Recall	F1	AP	
NO2	0.40±0.051	0.48±0.03	0.44±0.04	0.38±0.06	*Benchmarks*
Moran's I	0.44±0.04	0.71±0.03	0.54±0.04	0.49±0.06	
Moran's I on high NO2	0.65±0.03	0.69±0.03	0.67±0.03	0.61±0.06	
Linear SVM	0.44±0.03	0.83±0.02	0.57±0.03	0.61±0.06	*Linear models*
Logistic	0.44±0.03	0.84±0.02	0.58±0.03	0.61±0.06	
RBF SVM	0.47±0.03	0.86±0.02	0.61±0.03	0.74±0.03	*Non-linear models*
Random Forest	0.55±0.02	0.81±0.02	0.65±0.02	0.74±0.03	
XGBoost	0.77±0.03	0.58±0.04	0.66±0.03	**0.75±0.03**	