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Institute of Geodesy

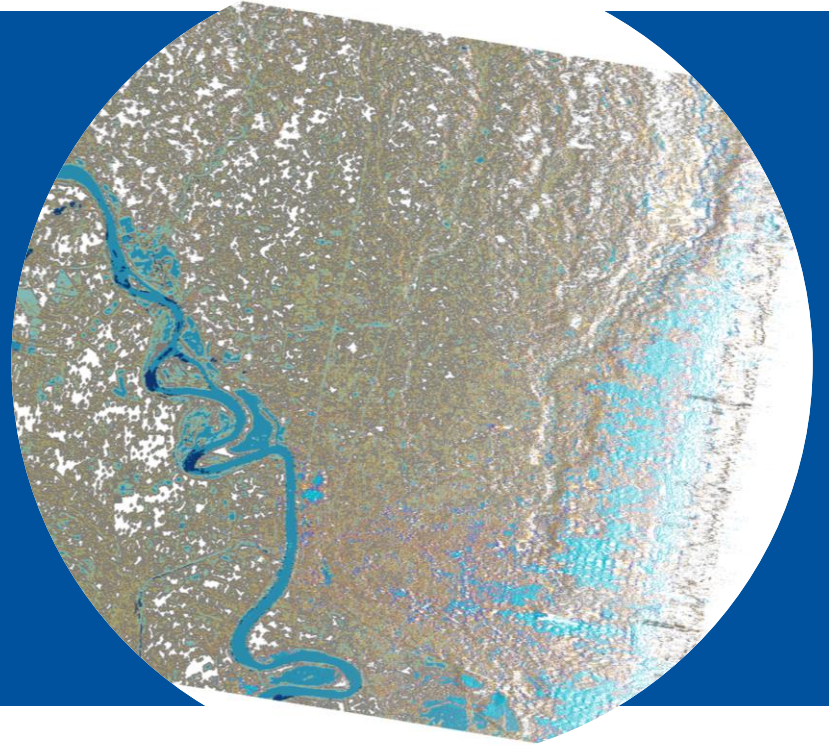
**ETH** zürich

# Improving surface type classification in SWOT PIXC Data to enhance inland water monitoring

MJ Tourian<sup>1</sup>, Danyang Zhao<sup>1</sup>, Omid Elmi<sup>1</sup>, Soheil Ettehadieh<sup>1</sup>, Junyang Gou<sup>2</sup>

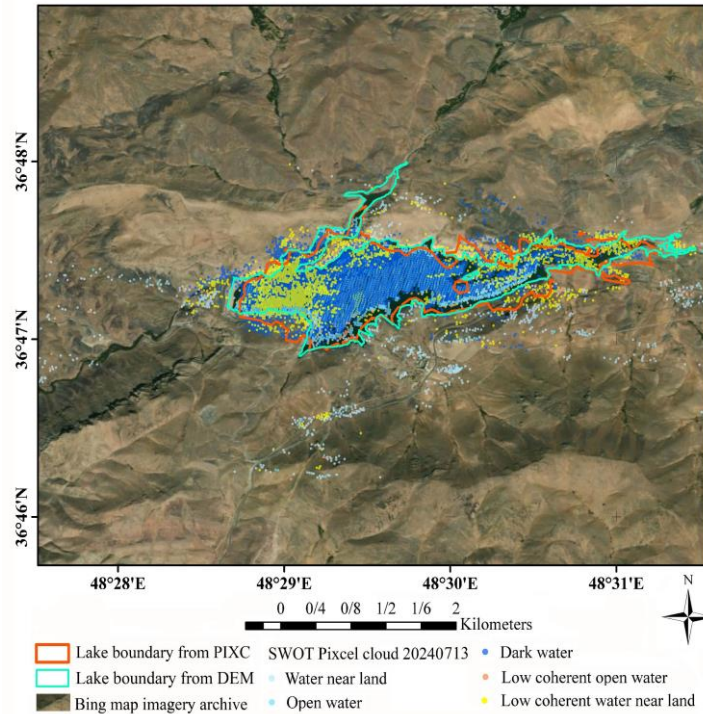
<sup>1</sup>University of Stuttgart, institute of Geodesy, Institute of Geodesy, Stuttgart, Germany

<sup>2</sup>Institute of Geodesy and Photogrammetry, ETH Zurich, Zurich, Switzerland

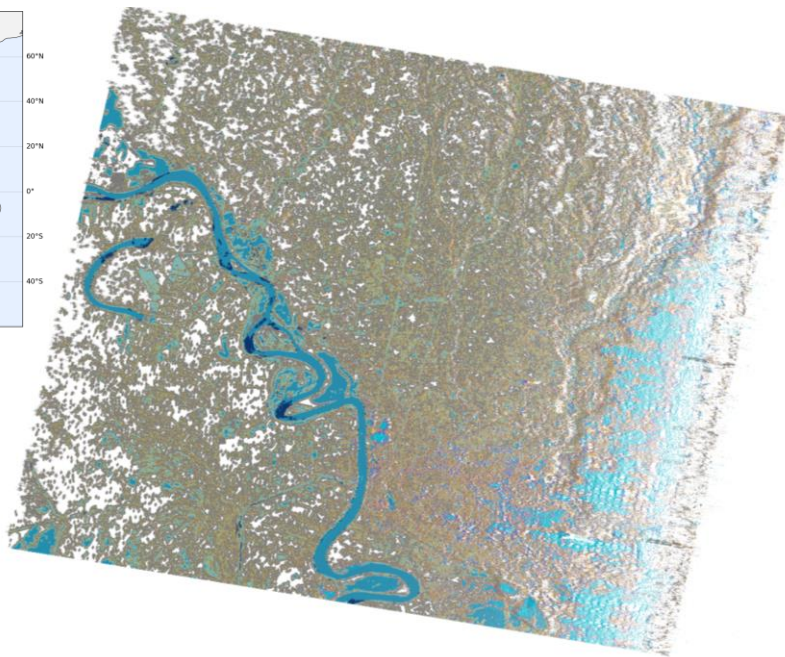
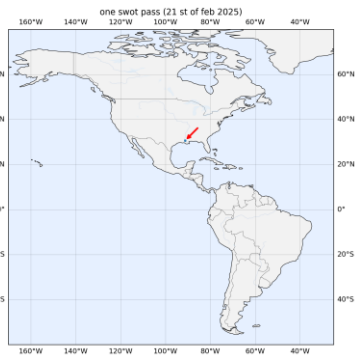


# Problem statement

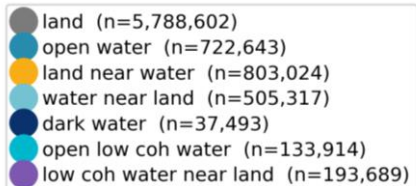
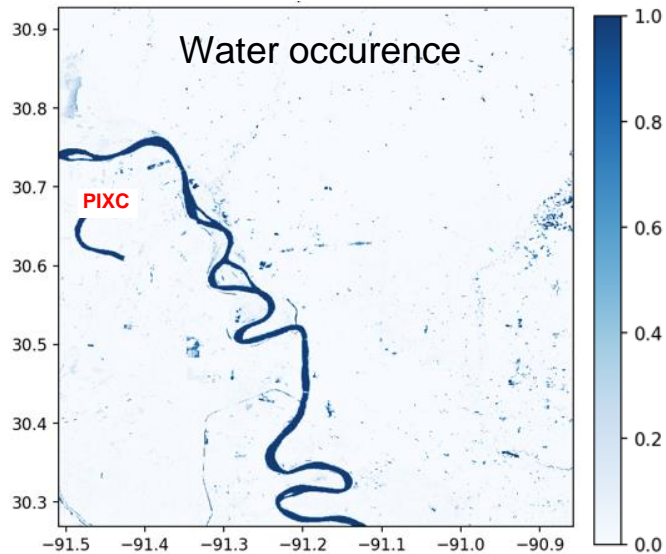
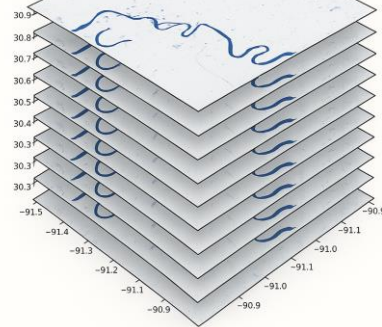
- Accurately deriving surface water extent from SWOT data appears to be a challenge



# Assessment of SWOT classification

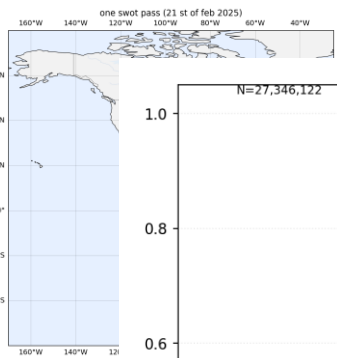
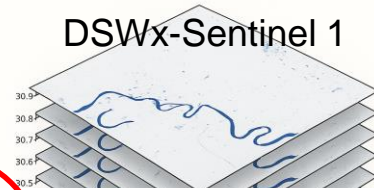


DSWx-Sentinel 1

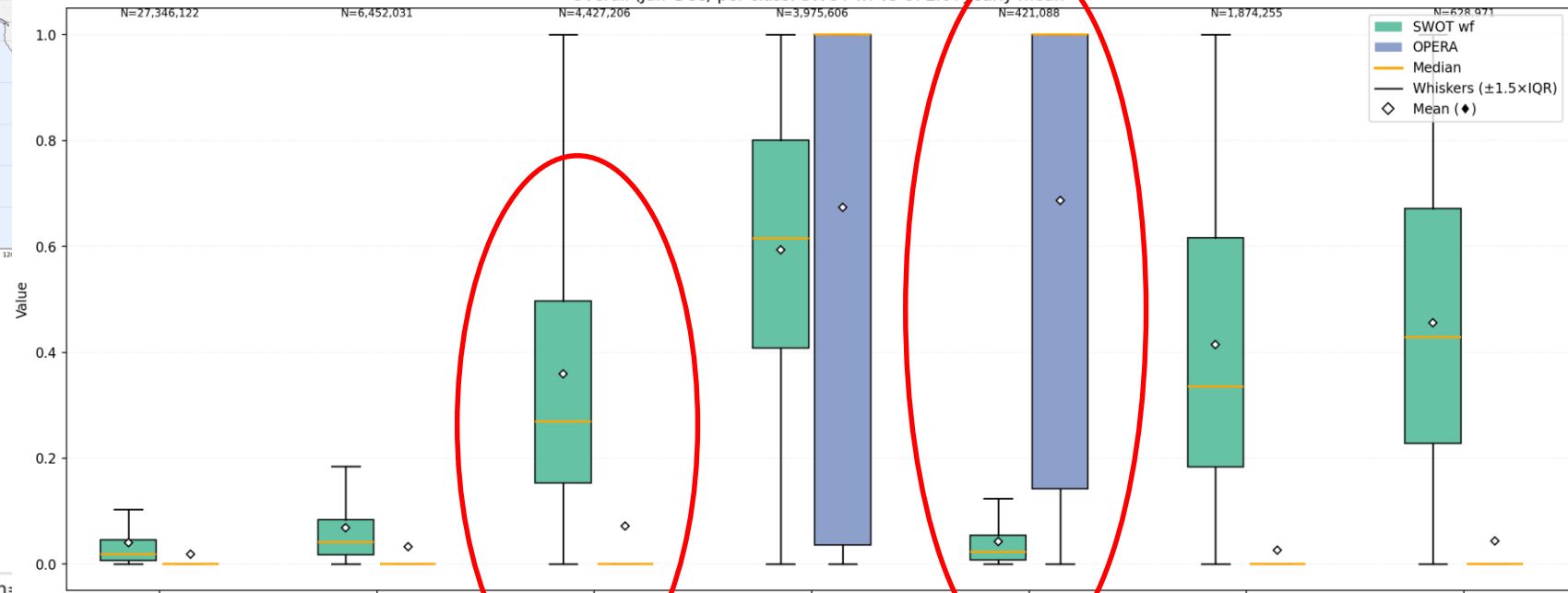


# Assessment of SWOT classification

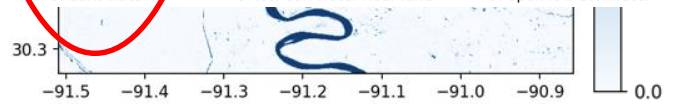
DSWx-Sentinel 1



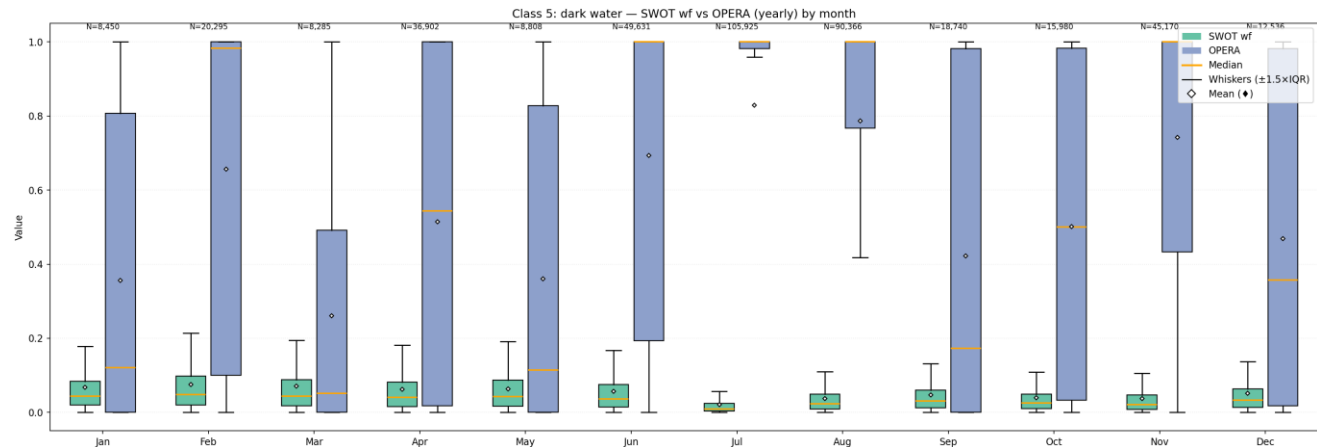
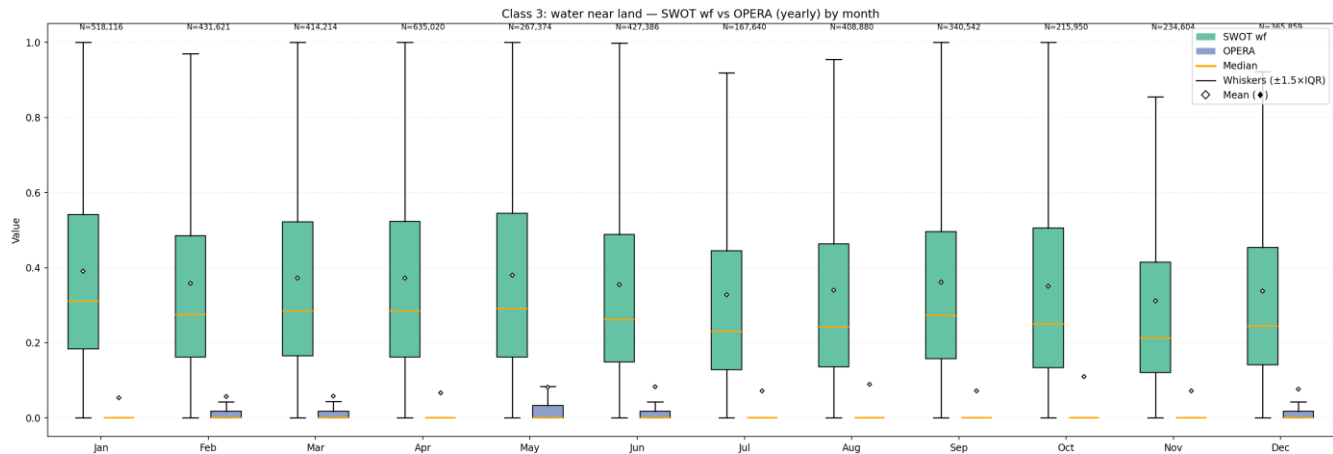
Overall (Jan-Dec) per class: SWOT wf vs OPERA yearly mean



- land (n=...)
- open wa...
- land near water (n=803,024)
- water near land (n=505,317)
- dark water (n=37,493)
- open low coh water (n=133,914)
- low coh water near land (n=193,689)

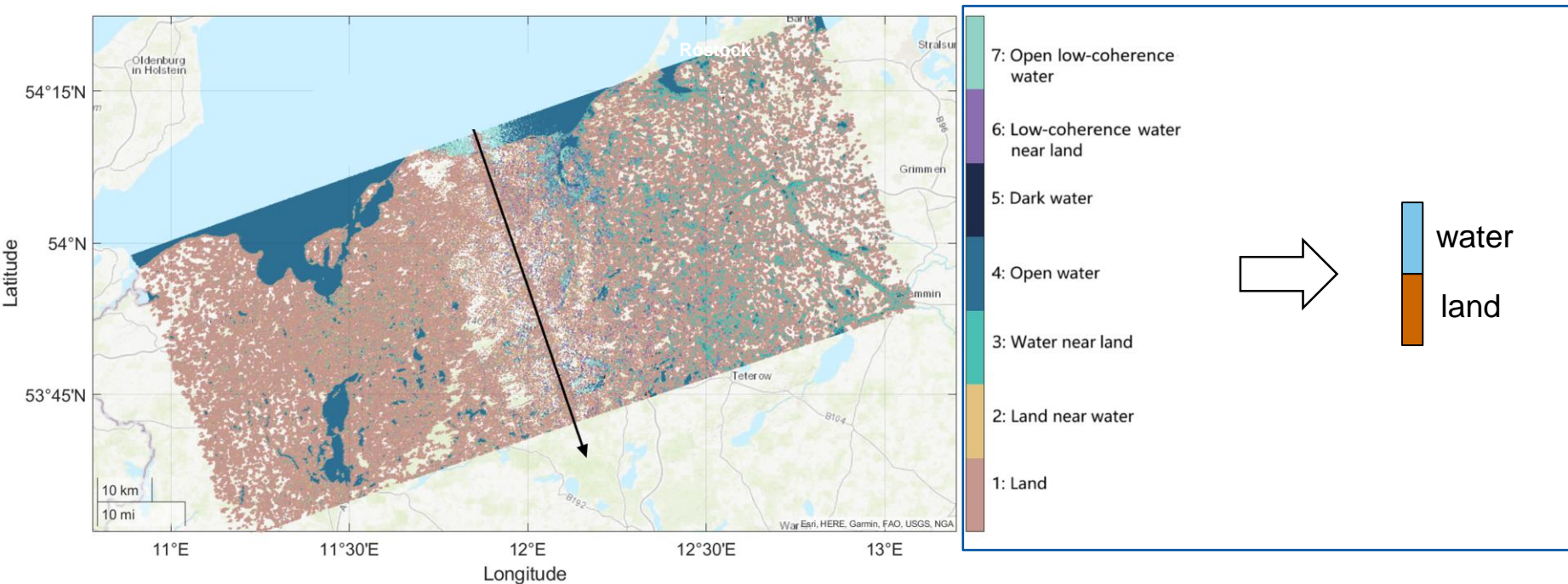


# Assessment of SWOT classification

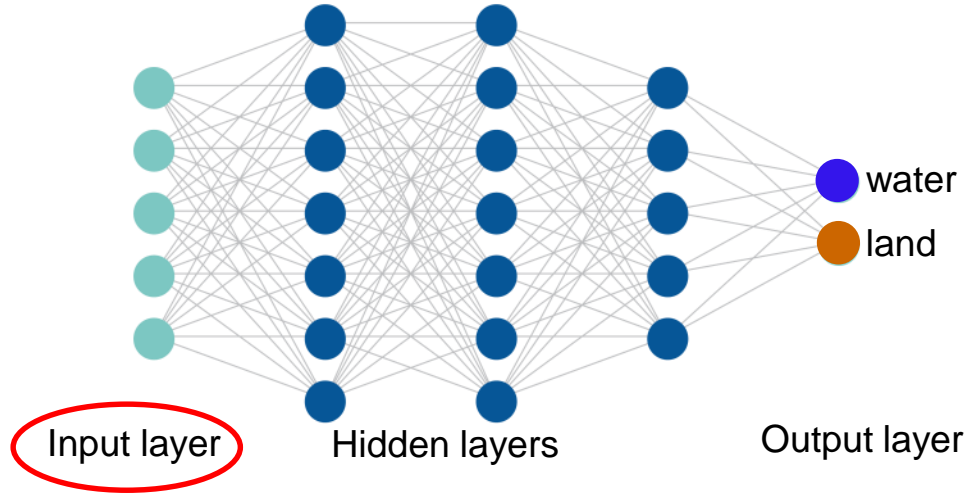


# Idea

Binary (re)classification of PIXC data using SWOT and auxiliary features with deep learning algorithms

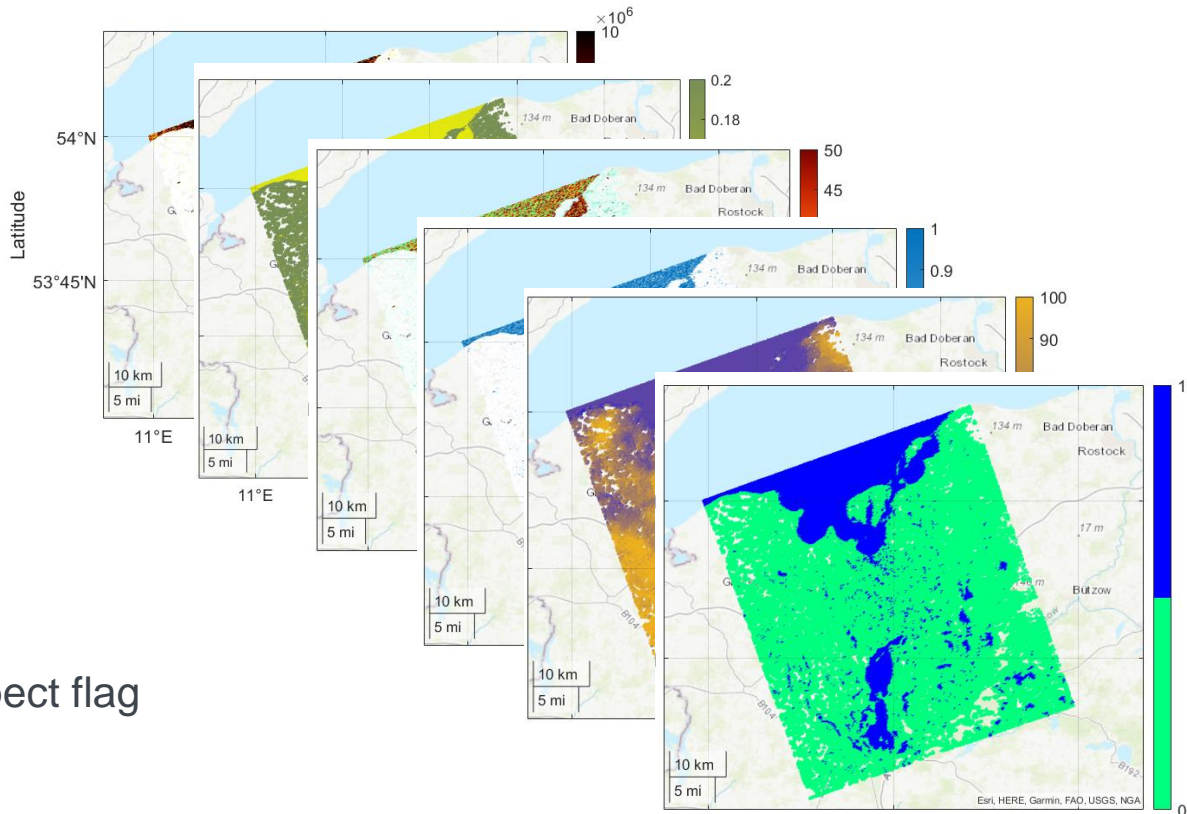


# Methodology

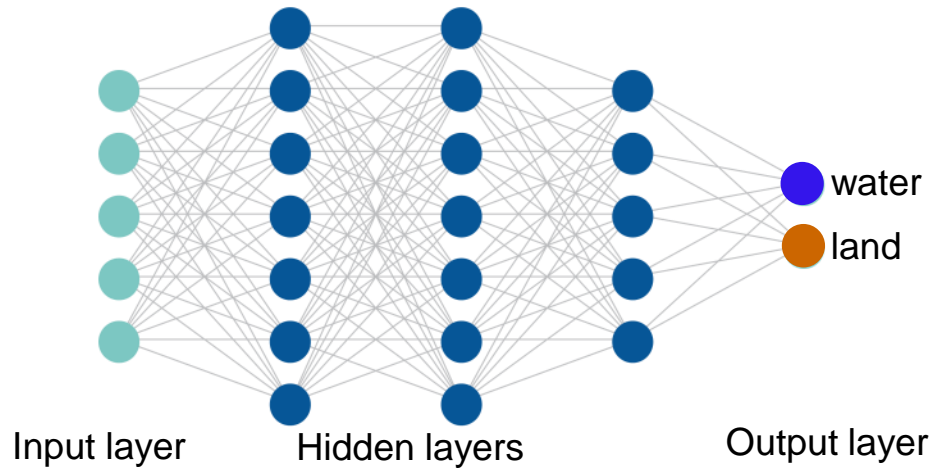


# Input layers

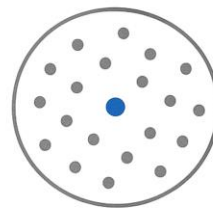
- Coherence power
- Phase noise std
- Sigma0
- Water fraction
- Height
- Phase unwrapping suspect flag
- Interferogram
- River flag, Lake flag, Effective number of medium looks, Cross track distance



# Methodology

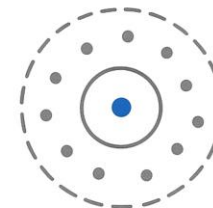


## 3 different modeling concepts



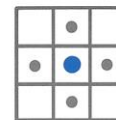
Single Point Model

Uses features from one point only



Nearest Features / Height Model

Uses features from N nearest points (N = 10, 25, 50)  
In height variant: only height feature used



CNN

Applies convolution over spatially arranged nearest features

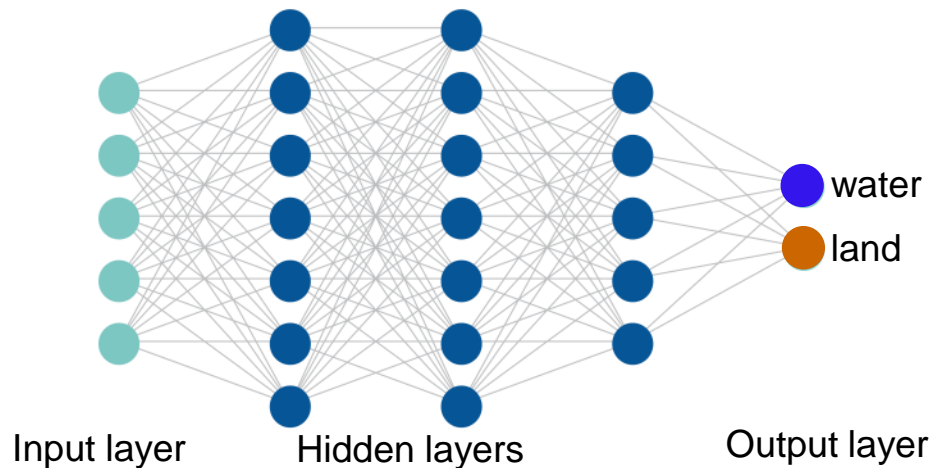
- Coherence power
- Phase noise std
- Sigma0
- Phase unwrapping suspect flag,
- Water fraction
- Height
- Interferogram
- River flag
- Lake flag
- Water occurrence
- Effective number of medium looks
- Cross track distance

Single Point Models  
Nearest Features/Height models  
Convolutional Nearest Features models

# Model setup

Model	Pixel Cloud size	Features in Model	Activation function
SP05F	1	Coherence power, Phase noise std, Sigma0, Phase unwrapping suspect flag, Water fraction	Leaky ReLU
SP06F	1	Coherence power, Phase noise std, Sigma0, Phase unwrapping suspect flag, Water fraction, Height	Leaky ReLU
SP10F	1	Coherence power, Phase noise std, Sigma0, Phase unwrapping suspect flag, Water fraction, Height, Interferogram, River flag, Lake flag, Water occurrence	Leaky ReLU
SP12F	1	Coherence power, Phase noise std, Sigma0, Phase unwrapping suspect flag, Water fraction, Height, Interferogram, River flag, Lake flag, Water occurrence, Effective number of medium looks, Cross track distance	Leaky ReLU
N04F-10	10	Coherence power, phase noise std, Sigma0, Phase unwrapping suspect flag	ReLU
N04F-25	25	Coherence power, phase noise std, Sigma0, Phase unwrapping suspect flag	ReLU
N04F-50	50	Coherence power, phase noise std, Sigma0, Phase unwrapping suspect flag	ReLU
NH-10	10	Height	ReLU
NH-25	25	Height	ReLU
NH-50	50	Height	ReLU
CN05F-10	10	Coherence power, phase noise std, Sigma0, Phase unwrapping suspect flag, Water fraction	Leaky ReLU
CN05F-25	25	Coherence power, phase noise std, Sigma0, Phase unwrapping suspect flag, Water fraction	Leaky ReLU
CN05F-50	50	Coherence power, phase noise std, Sigma0, Phase unwrapping suspect flag, Water fraction	Leaky ReLU
CN06F-10	10	Coherence power, phase noise std, Sigma0, Phase unwrapping suspect flag, Water fraction, Height	Leaky ReLU
CN06F-25	25	Coherence power, phase noise std, Sigma0, Phase unwrapping suspect flag, Water fraction, Height	Leaky ReLU
CN06F-50	50	Coherence power, phase noise std, Sigma0, Phase unwrapping suspect flag, Water fraction, Height	Leaky ReLU
CN10F-10	10	Coherence power, Phase noise std, Sigma0, Phase unwrapping suspect flag, Water fraction, Height, Interferogram, River flag, Lake flag, Water occurrence	Leaky ReLU
CN10F-25	25	Coherence power, Phase noise std, Sigma0, Phase unwrapping suspect flag, Water fraction, Height, Interferogram, River flag, Lake flag, Water occurrence	Leaky ReLU
CN10F-50	50	Coherence power, Phase noise std, Sigma0, Phase unwrapping suspect flag, Water fraction, Height, Interferogram, River flag, Lake flag, Water occurrence	Leaky ReLU
CN12F-10	10	Coherence power, Phase noise std, Sigma0, Phase unwrapping suspect flag, Water fraction, Height, Interferogram, River flag, Lake flag, Water occurrence, Effective number of medium looks, Cross track distance	Leaky ReLU
CN12F-25	25	Coherence power, Phase noise std, Sigma0, Phase unwrapping suspect flag, Water fraction, Height, Interferogram, River flag, Lake flag, Water occurrence, Effective number of medium looks, Cross track distance	Leaky ReLU
CN12F-50	50	Coherence power, Phase noise std, Sigma0, Phase unwrapping suspect flag, Water fraction, Height, Interferogram, River flag, Lake flag, Water occurrence, Effective number of medium looks, Cross track distance	Leaky ReLU

# Methodology



- Coherence power
- Phase noise std
- Sigma0
- Phase unwrapping suspect flag,
- Water fraction
- Height
- Interferogram
- River flag
- Lake flag
- Water occurrence
- Effective number of medium looks
- Cross track distance



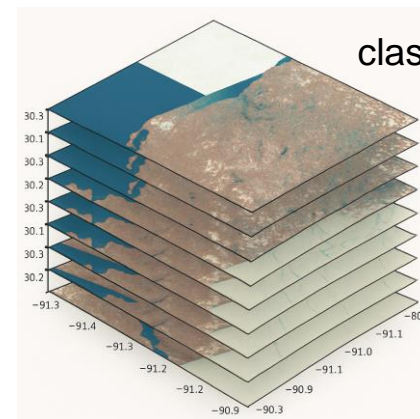
Single Point Models  
Nearest Features/Height models  
Convolutional Nearest Features models

Training on one epoch and applying on all epoches



Training & model generation

Loss function: Cross Entropy Loss



# Data preprocessing and DL training

## Preprocessing:

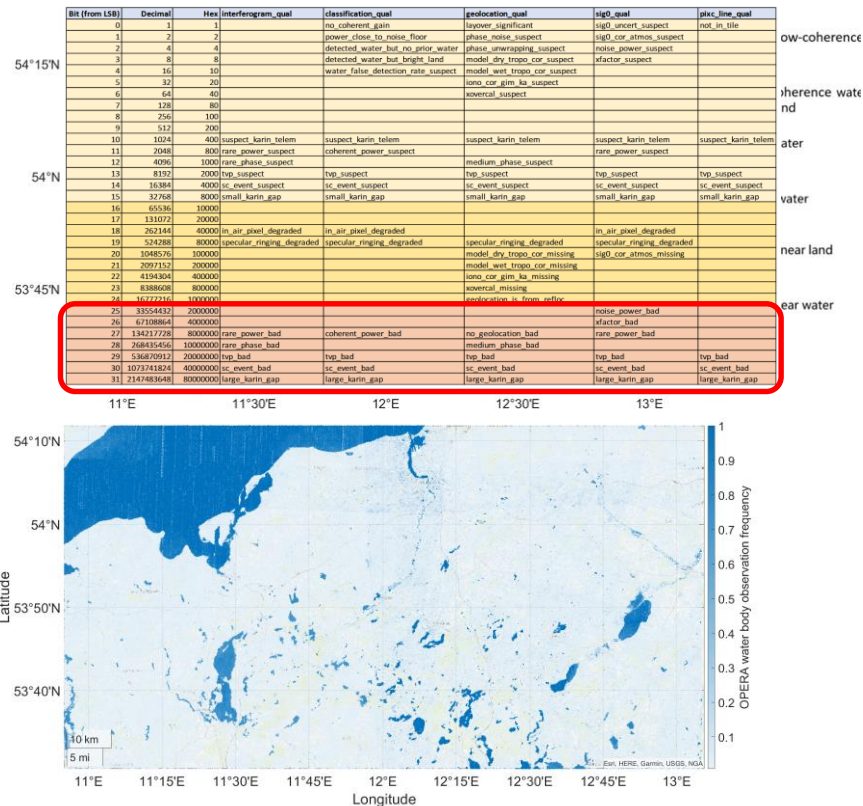
- Removing data with cross track distance < 10km and > 60km
- Removing data with bit flag above 24

## Training:

- One epoch data of SWOT PIXC (version C) on June 2024
- Mean water fraction from DSWx (Sentinel 2, Landsat 8) April 2023-August 2025



- Water occurrence > 0.5 → water
- Water occurrence = 0 → land



**ST2025HS1\_008 - Evaluation of the Water Masks Generated by the SWOT Satellite and Comparison with Optical Sensors**

Maurício Cordeiro (National Water and Sanitation Agency (ANA)), Santiago Pena-Luque (CNES), Renato Frasson (JPL), Mohammad J. Tourian (University of stuttgart), Tati de Almeida (UNB), Daniel Moreira (SGB), Fabrice Papa (IRD)

# Results

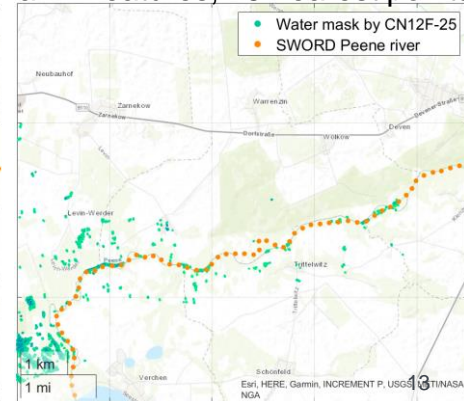
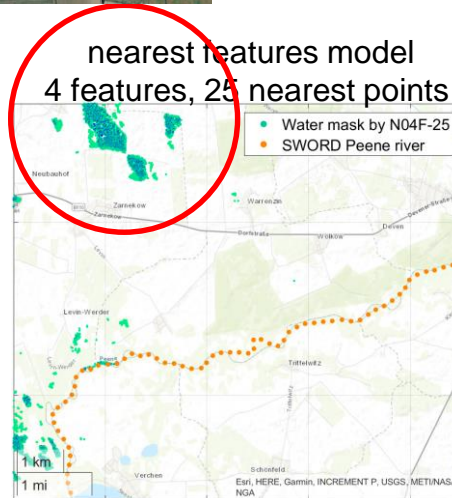
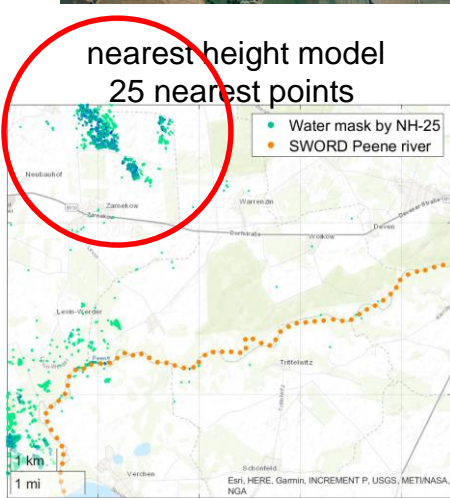
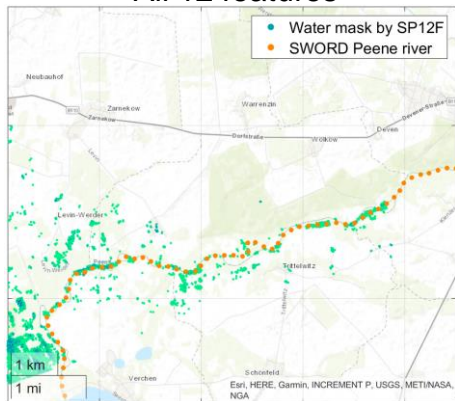


single point model  
All 12 features

nearest height model  
25 nearest points

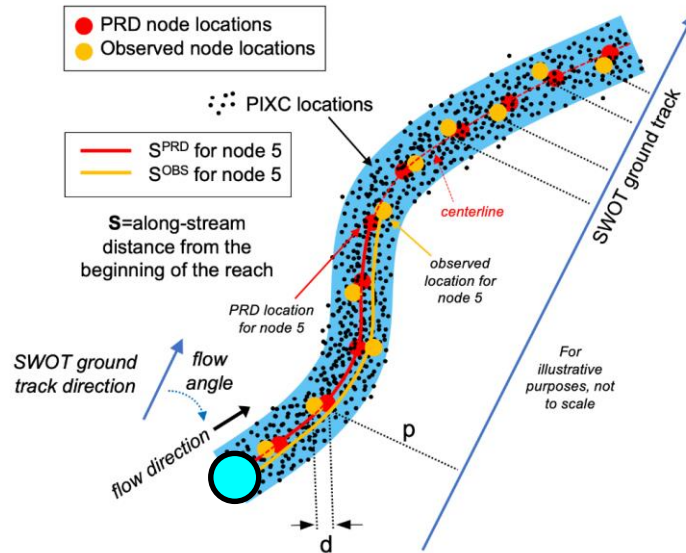
nearest features model  
4 features, 25 nearest points

CNN model  
all 12 features, 25 nearest points

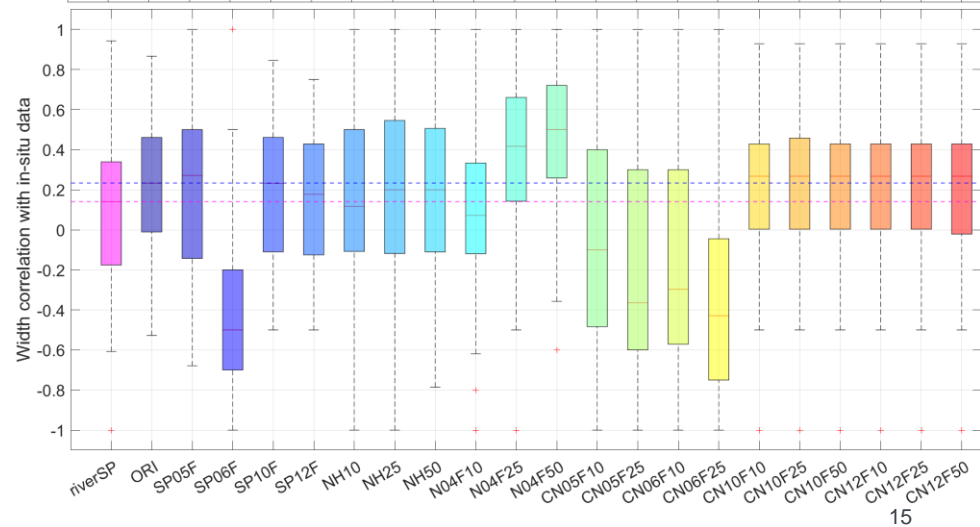
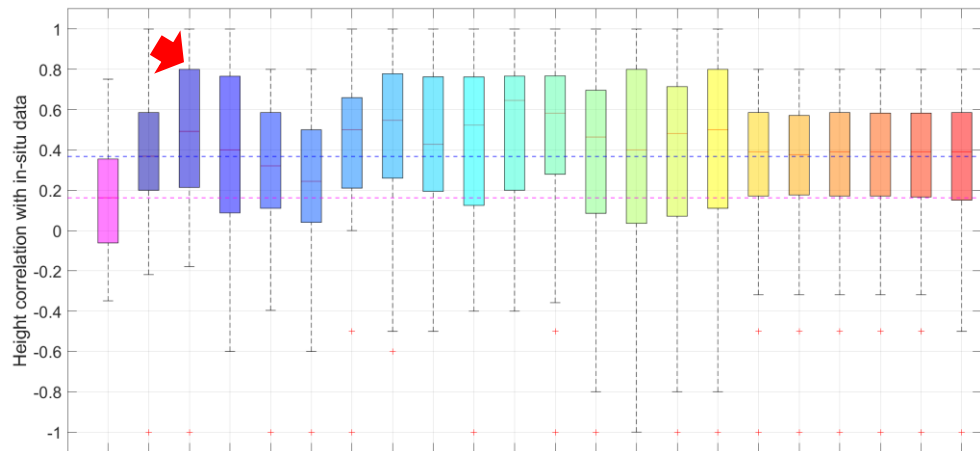
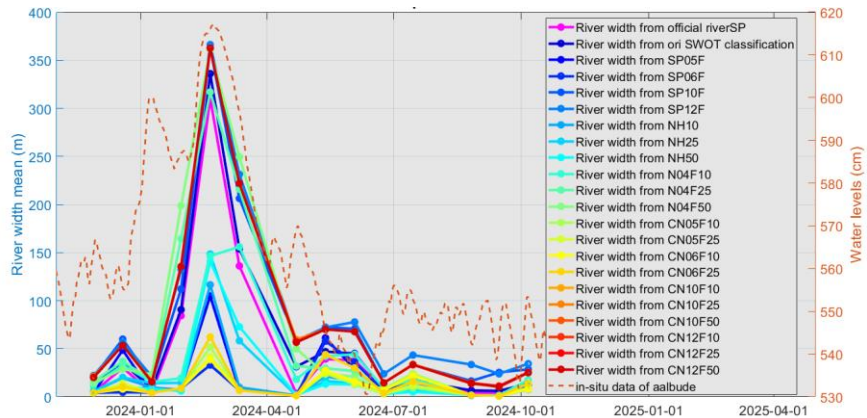


# Validation method

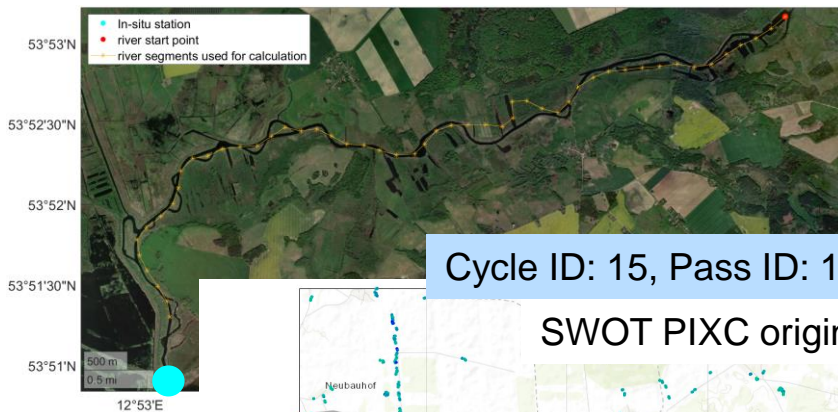
- RiverObs is used to generate width and height at the node level
- Node **height** and **width** are compared against in situ water level data



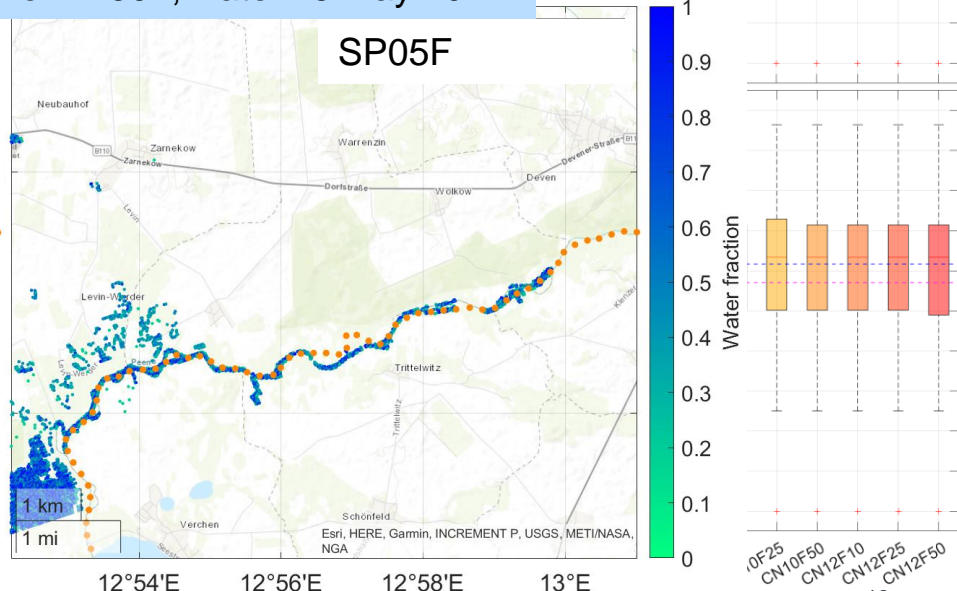
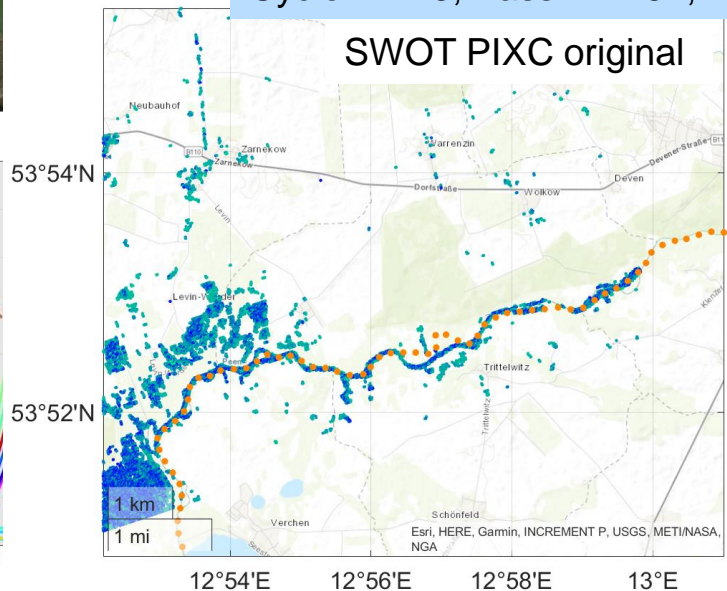
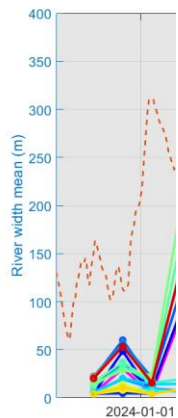
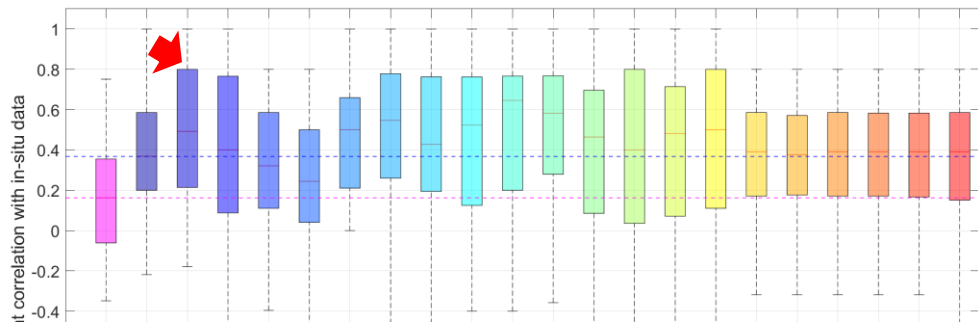
# Validation against in situ data



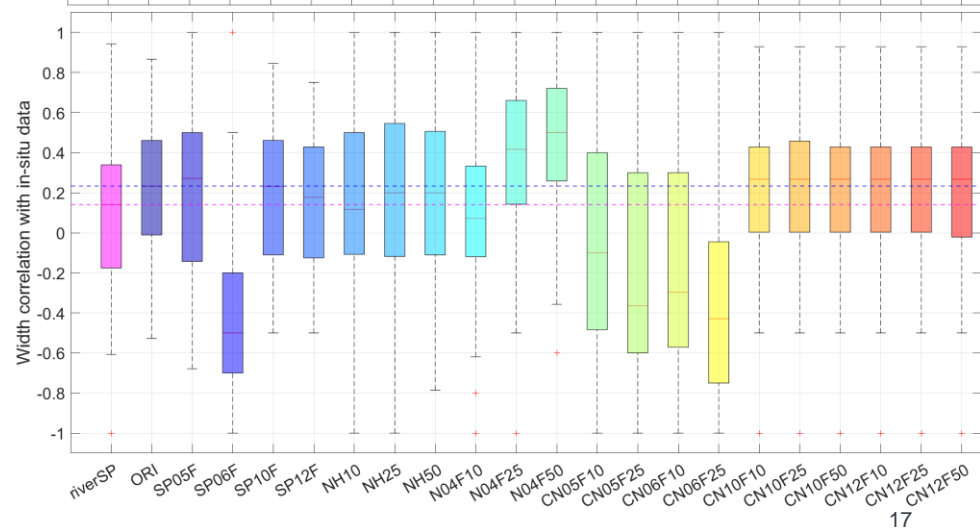
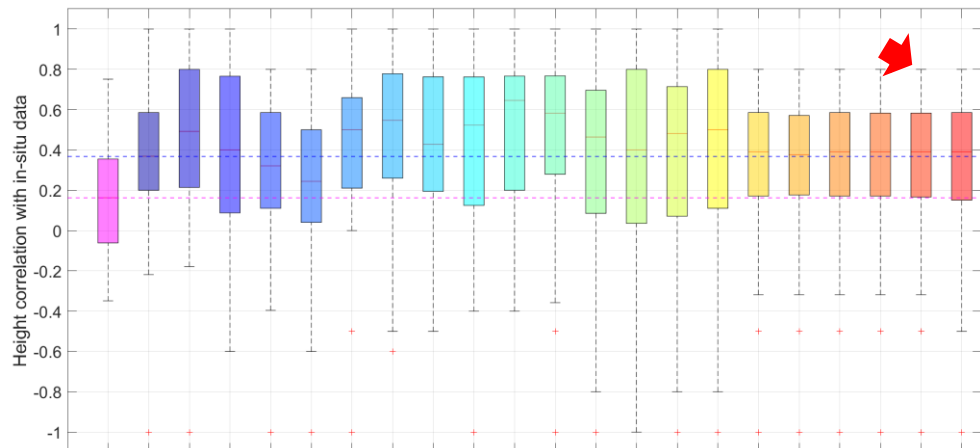
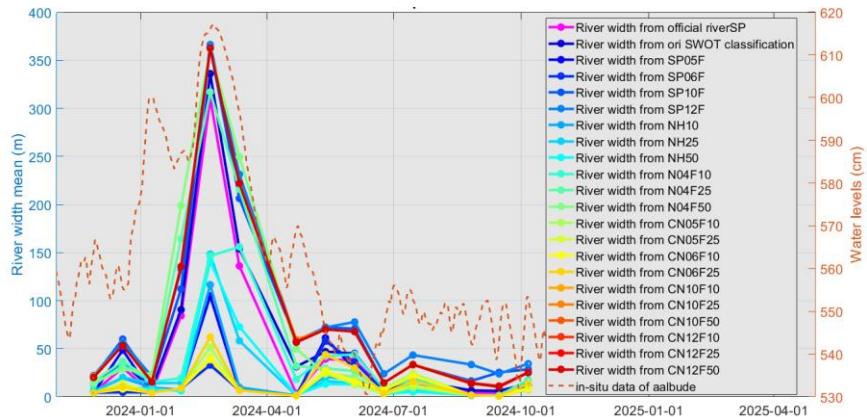
# Validation against in situ data



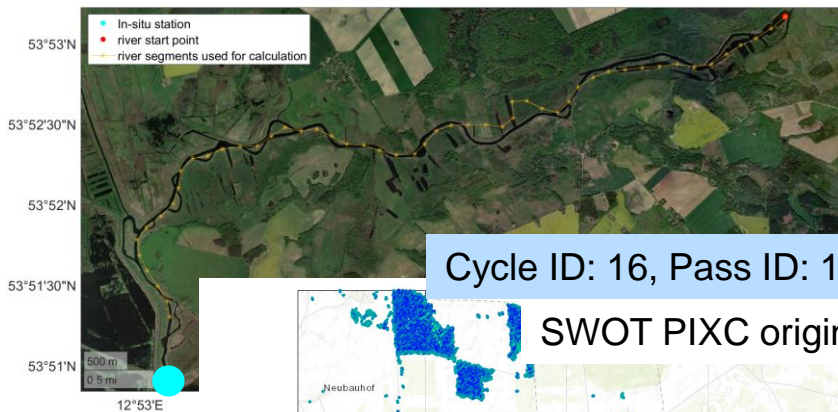
Cycle ID: 15, Pass ID: 152, Tile ID: 59L, Date: 13 May 2024



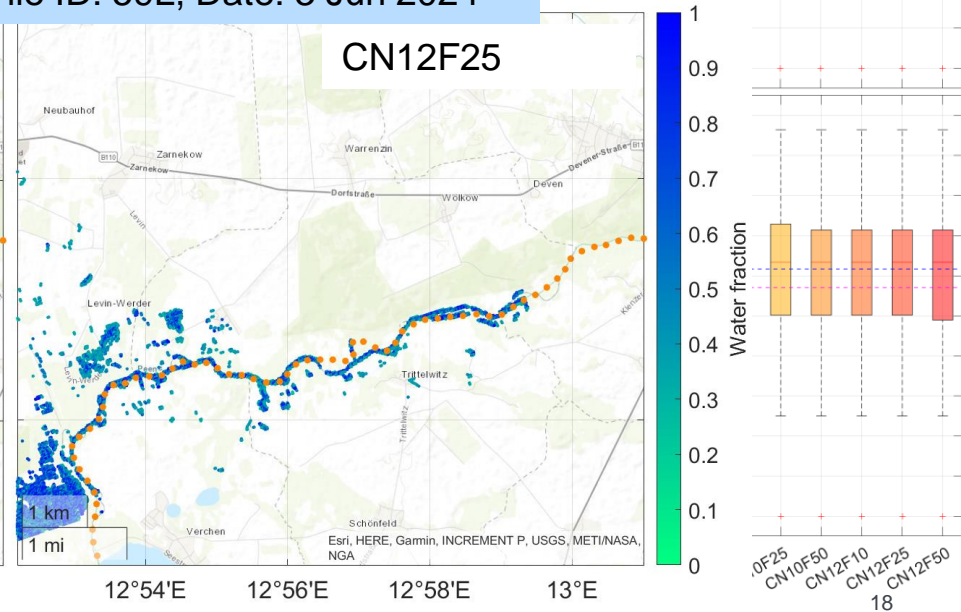
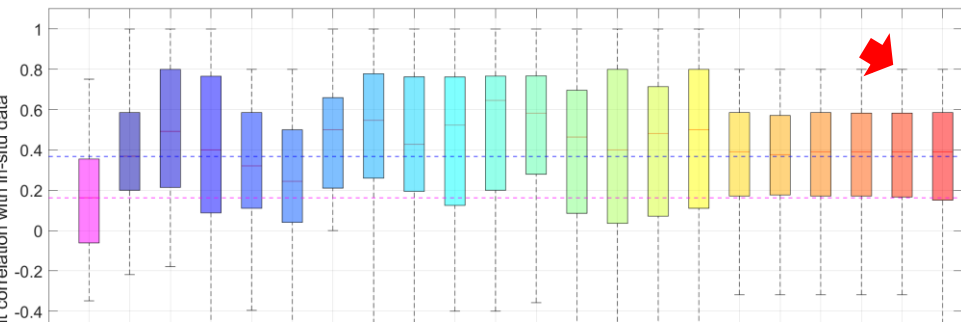
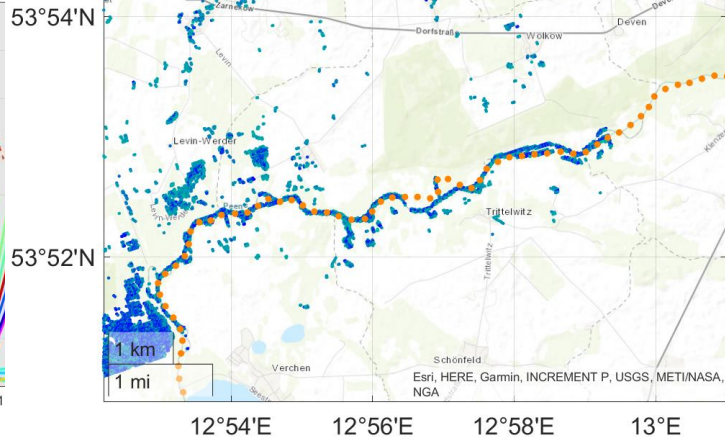
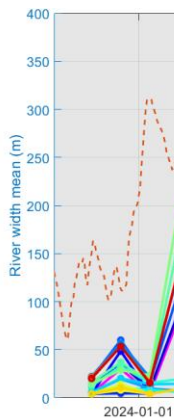
# Validation against in situ data



# Validation against in situ data



Cycle ID: 16, Pass ID: 152, Tile ID: 59L, Date: 3 Jun 2024

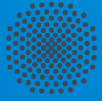


## Summary and conclusion

- The water fraction estimates for points in the *water near land* class seem to be overestimated, while those for points in the *dark water* class appear to be underestimated.
- We developed and evaluated a series of deep learning models for the binary classification of SWOT measurements (i.e., water vs. land). The models are grouped into four categories based on pixel cloud size and feature complexity:
  - **SP Models (1-point):** Single-point models using different numbers of features.
  - **Nearest Feature Models:** Medium-complexity models based on nearby feature information.
  - **Nearest Height Models:** Use only height as input and serve as a benchmark for evaluating the value of elevation data.
  - **CNN Models:** The most comprehensive models, incorporating different numbers of features.
- The Nearest Feature and NH models do not perform well.
- Most of the Single Point and CNN models yield better results than the latest version of RiverSP when applied to rivers.

### Outlook:

- Apply the approach to a larger dataset to assess the generalizability of the trained model.
- Making the codes and the model available



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# Thank you!



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