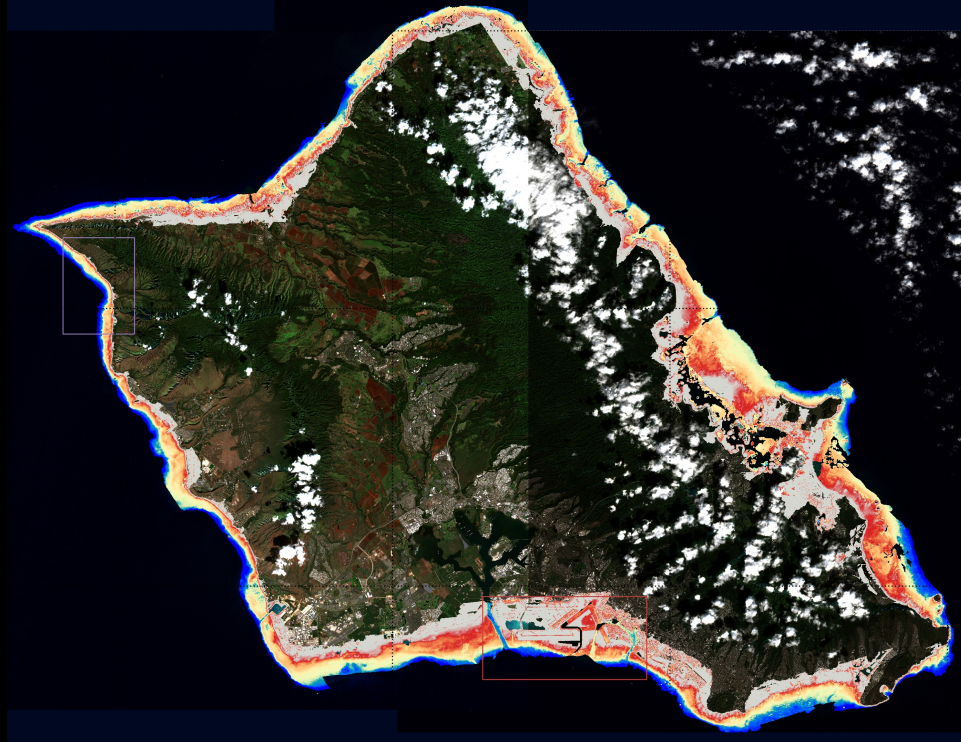


Convolutional Neural Networks for Satellite-Derived Bathymetry



Outline

- Introduction
- Related work
- Methodology
- Experiments and results
- Conclusions

Introduction

What is bathymetry?



Study of the water beds



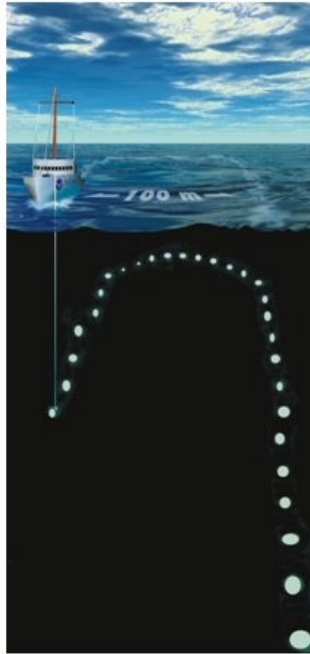
Bathymetry surveys reveal the terrain of water bed



Essential for coastal management and research

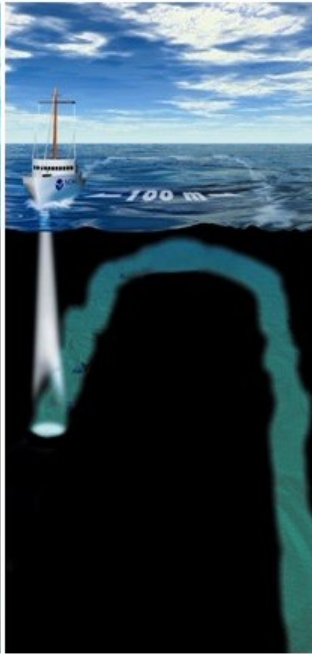
How to get bathymetry data?

Leadline



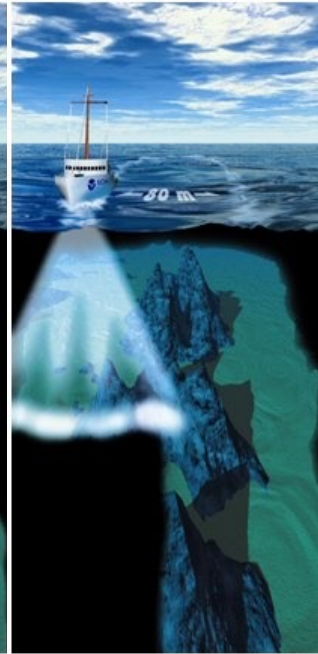
NOAA, 2016

SBES



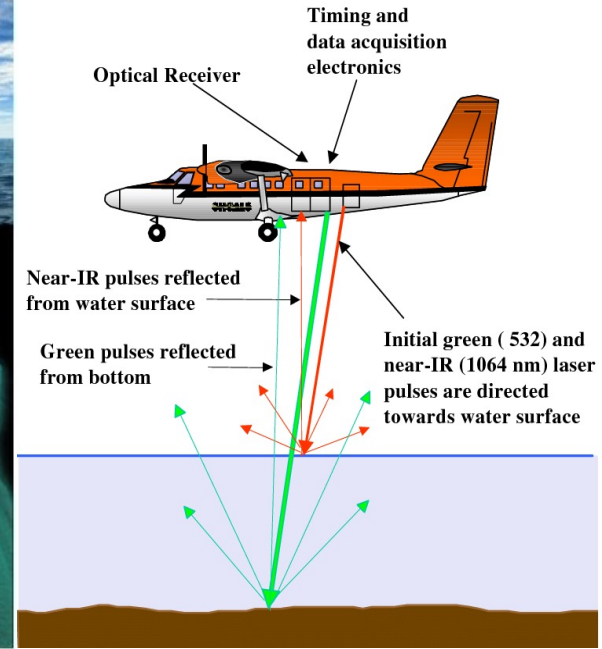
NOAA, 2016

MBES



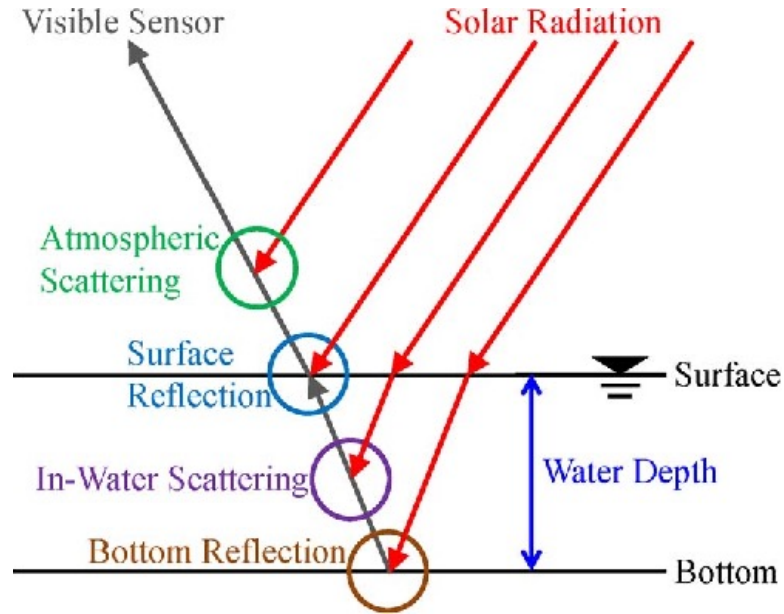
NOAA, 2016

LiDAR



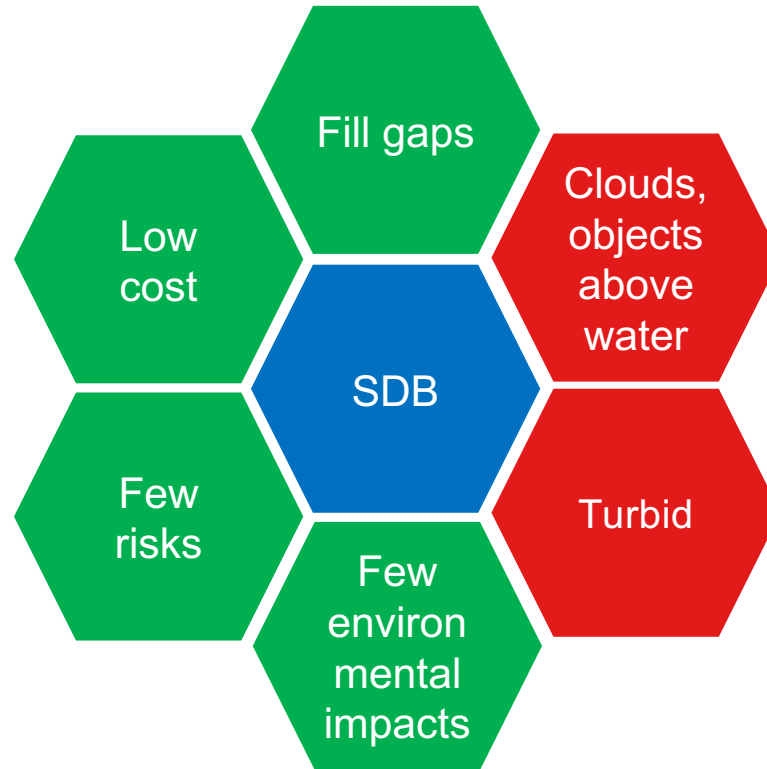
LaRocque and West, 1999

Satellite-Derived Bathymetry



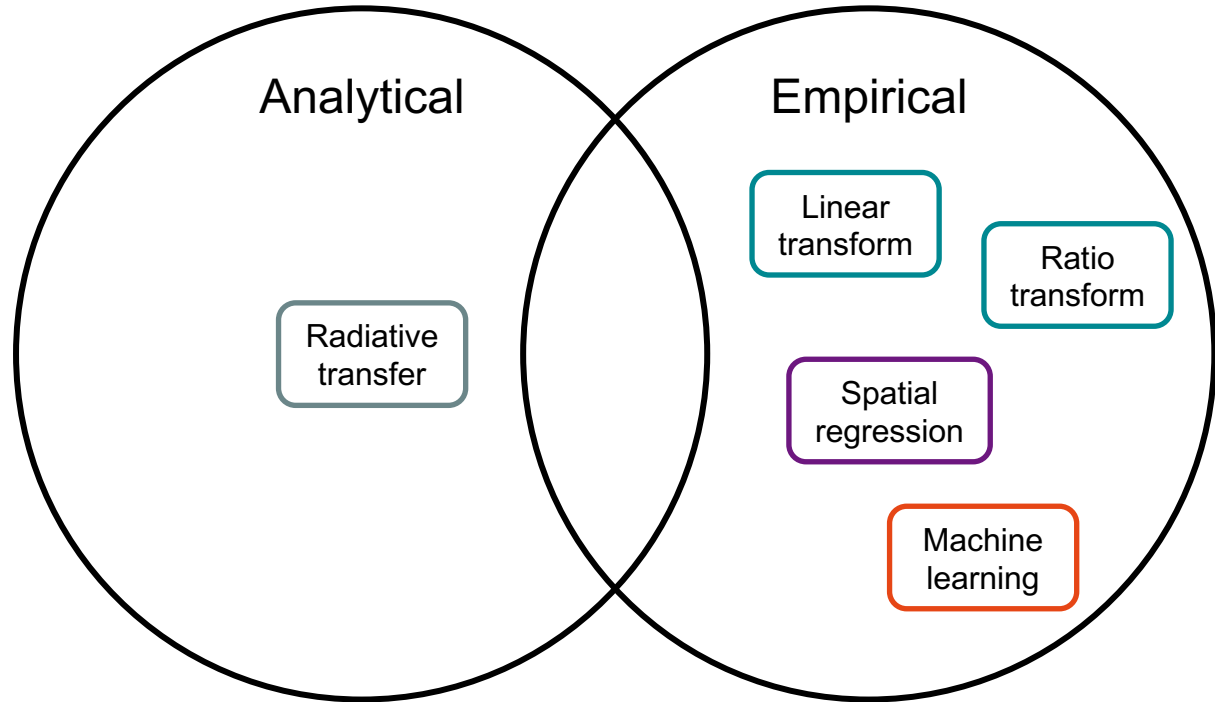
Kanno et al., 2012

Why SDB?

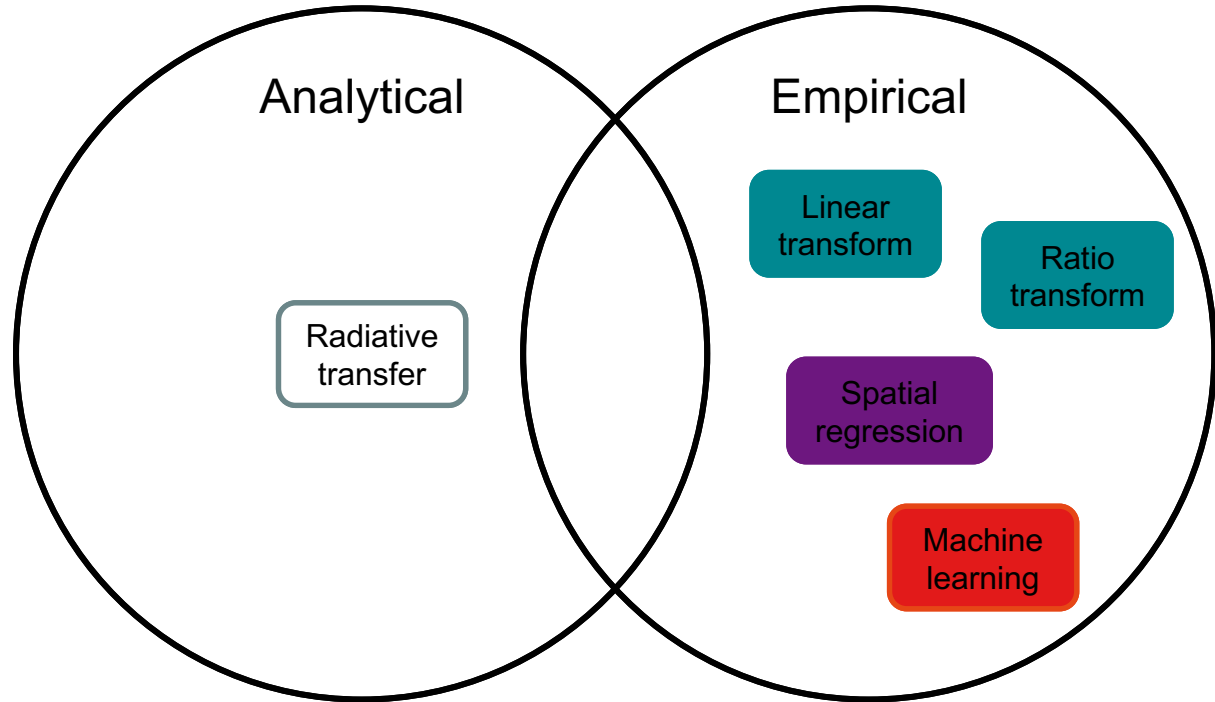


Related work

SDB methods



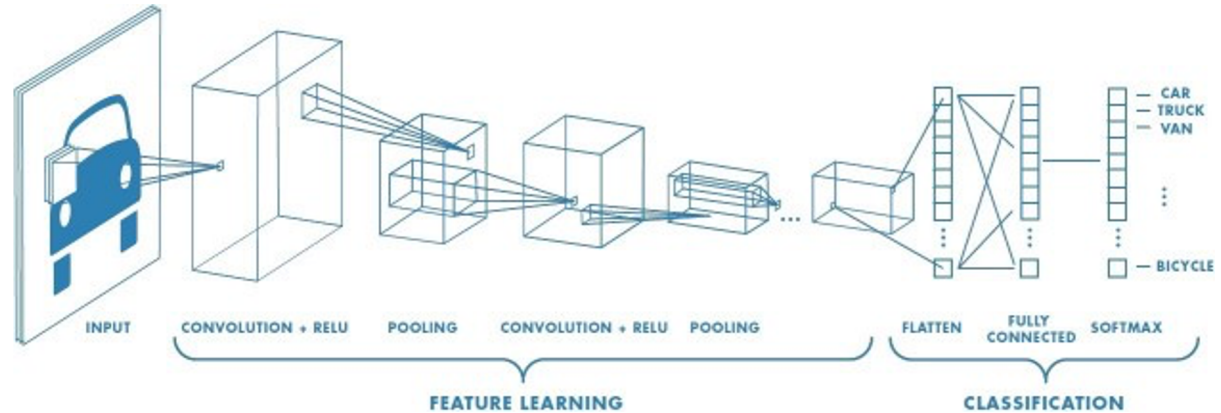
SDB methods



Factors to consider

- Nonlinearity due to bottom types/noise
- Spatial correlation

Convolutional Neural Networks



Research objective

- To develop convolutional neural networks that extract accurate water depth in shallow water areas

Research questions

Main question:

- To what extent can convolutional neural networks be used for accurate shallow water depth extraction using Sentinel-2 satellite images?

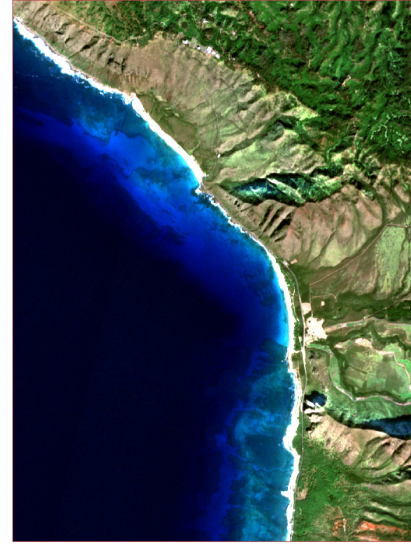
Sub questions:

- What kind of pre-processing is needed for the data sets?
- What kind of CNN architecture can be used for SDB?
- What is the accuracy of the method?
- To what extent can the pretrained model be reused?

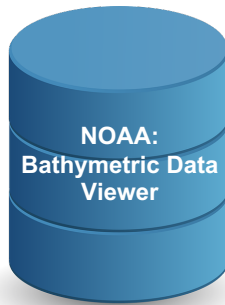
Methodology

Study areas

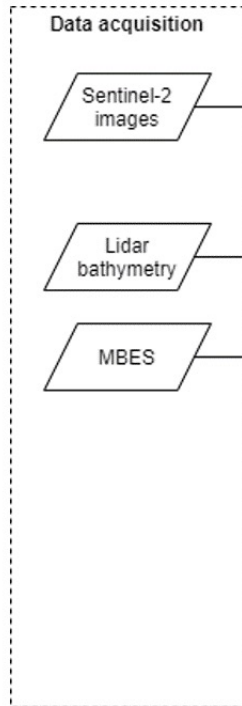
- Puerto Rico
- Key West
- Hawaii



Data



Workflow



Workflow

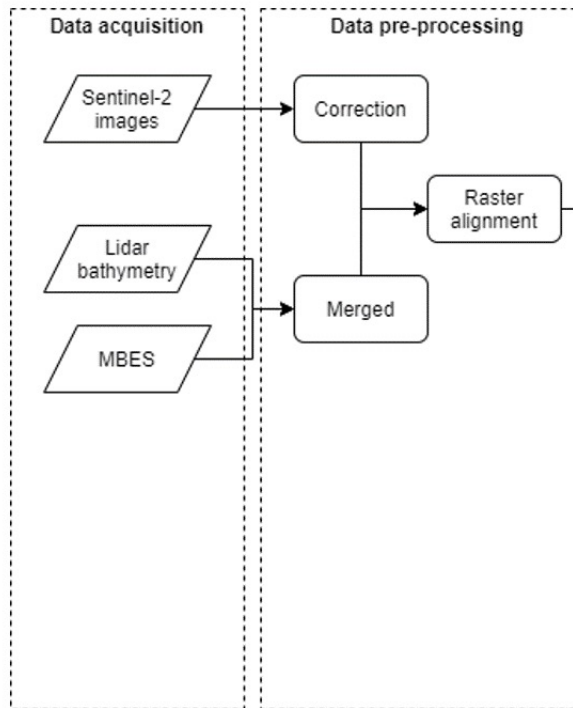
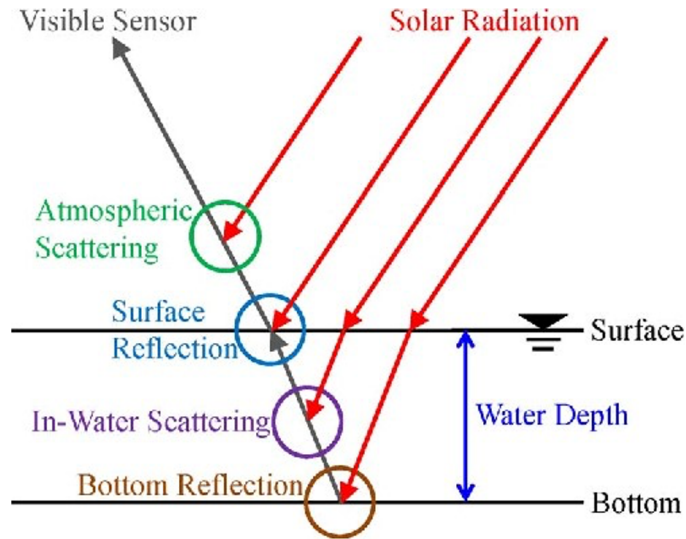
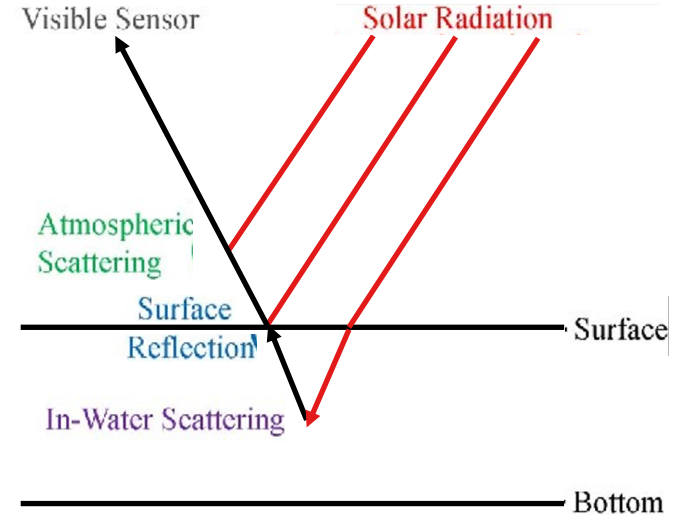


Image correction

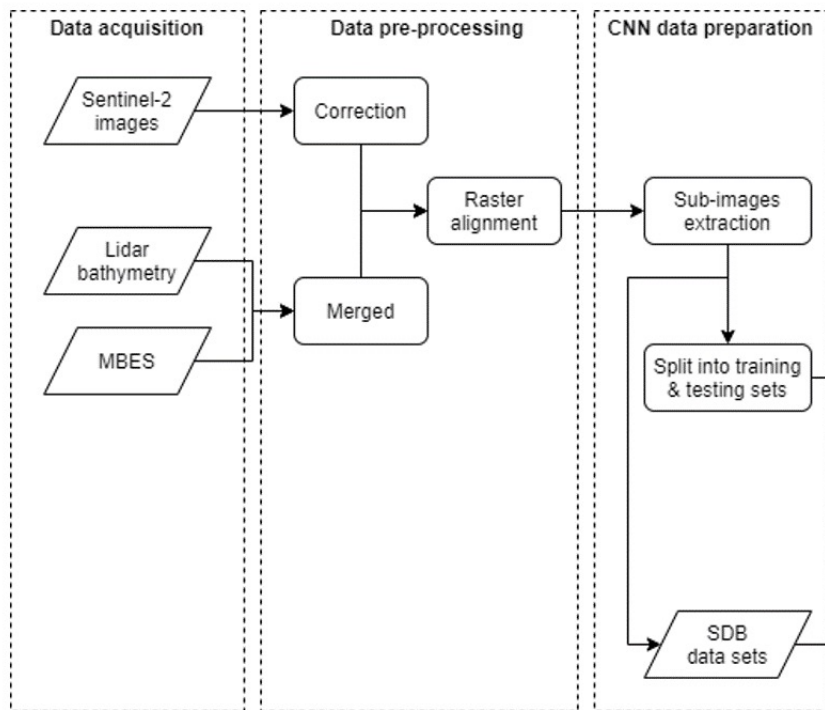


Shallow water

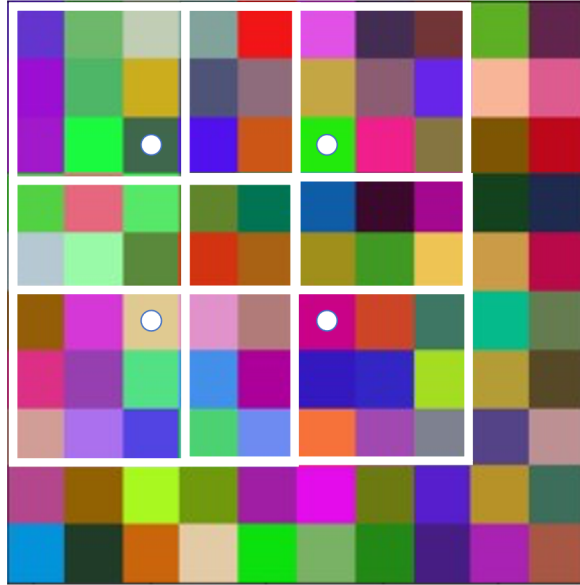


Deep water

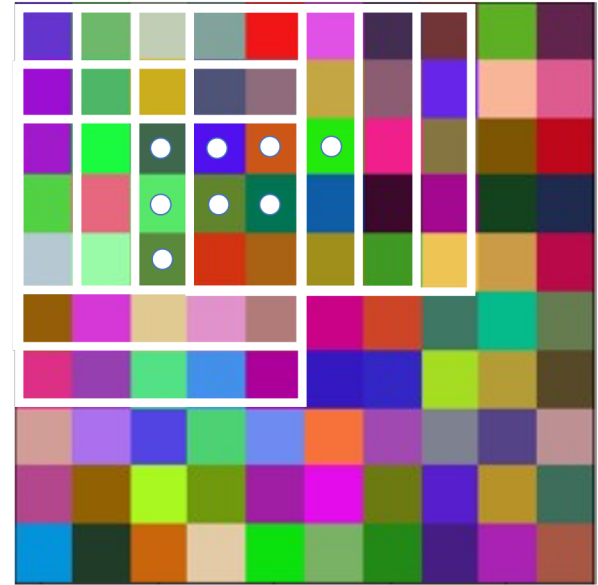
Workflow



Sub-images extraction

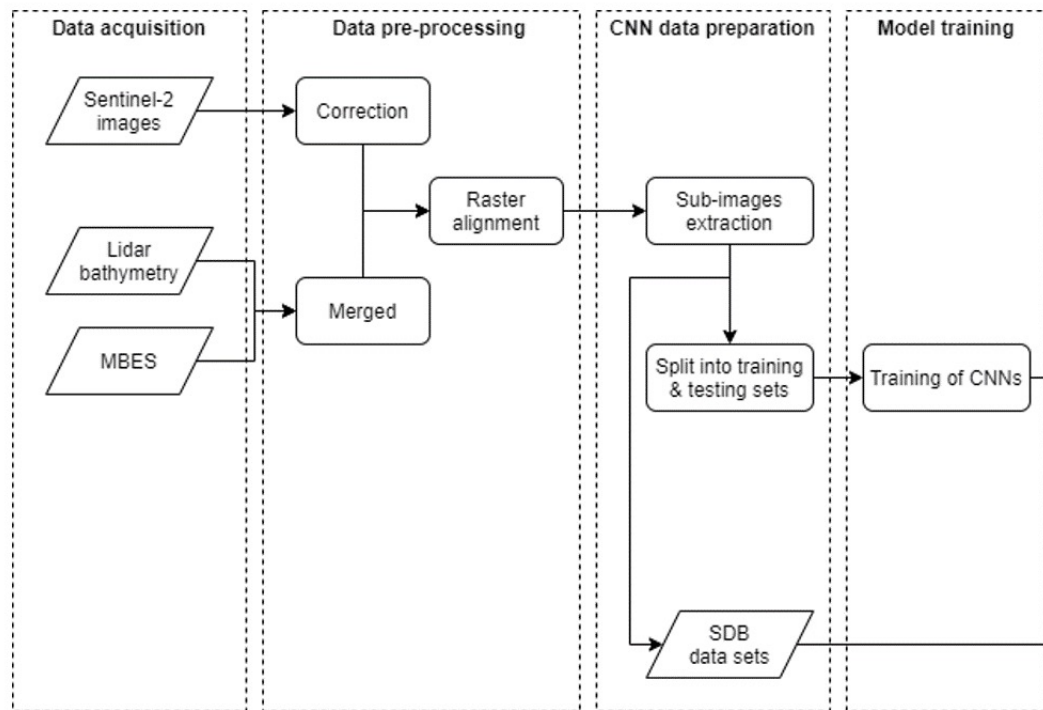


Sub-images for training and testing

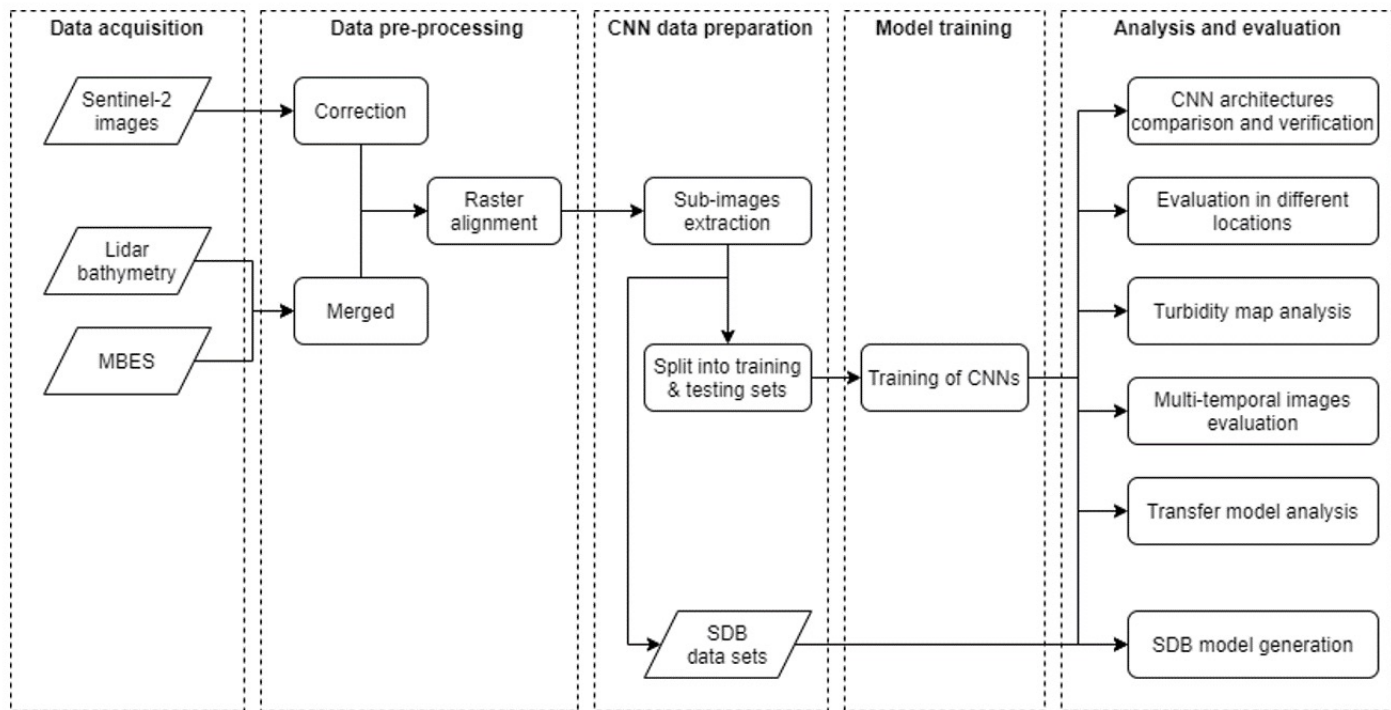


Sub-images for SDB model generation

Workflow



Workflow



Experiment #1: CNN architectures comparison and verification

Setup

Study area

CNN architecture

AOI-1

Layer	CNN1	CNN2	CNN3	CNN4
Conv2D	2x	2x	3x	3x
Kernel	2x2	2x2	3x3	3x3
Pooling	No	Yes	No	Yes

Window size

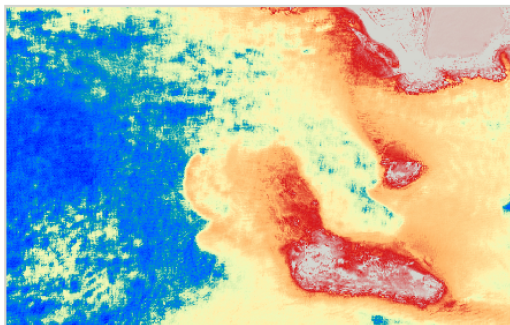
5x5, 7x7, 9x9

Band combination

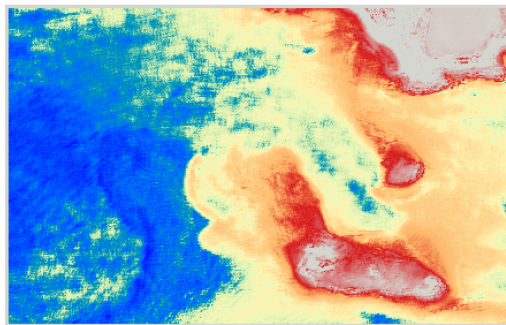
RGB, RGBN, RGBNSS, All bands

Window sizes

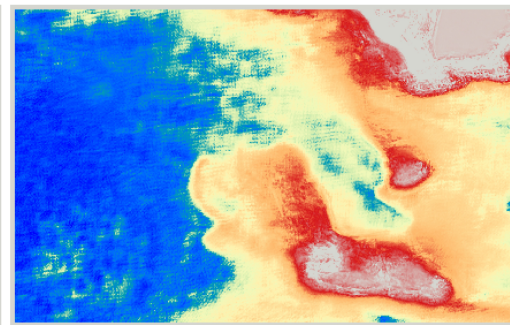
Models	5x5		7x7		9x9	
	RMSE	R2	RMSE	R2	RMSE	R2
CNN1	1.59	0.91	1.58	0.92	1.55	0.93
CNN2	1.94	0.89	1.63	0.91	1.55	0.93
CNN3			1.53	0.92	1.48	0.94
CNN4					1.64	0.90



5x5



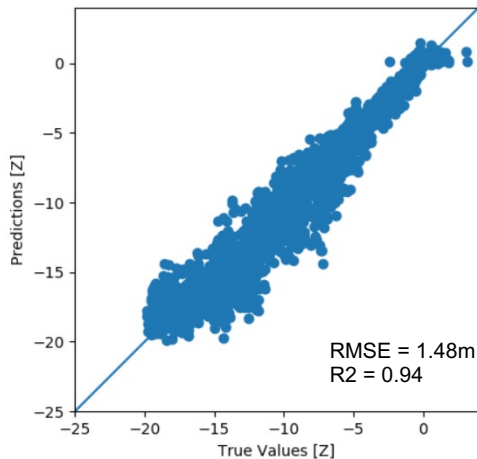
7x7



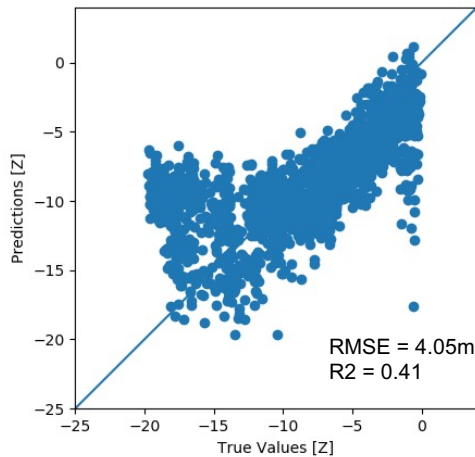
9x9

Depth (m) ■ -20 ■ -18 ■ -16 ■ -14 ■ -12 ■ -10 ■ -8 ■ -6 ■ -4 ■ -2 ■ 0

Comparison to the linear transform

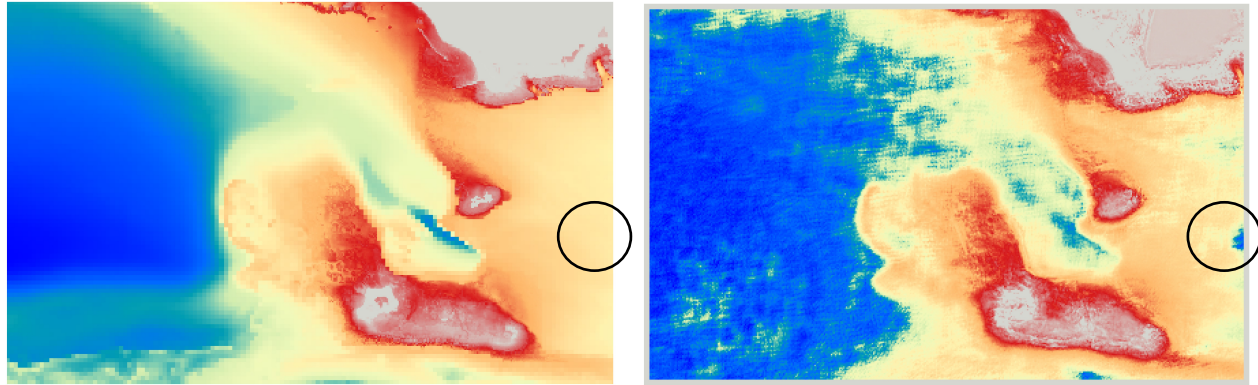


CNN

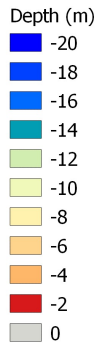
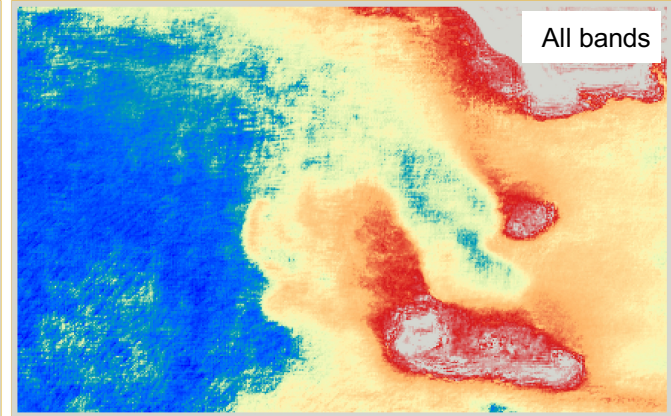
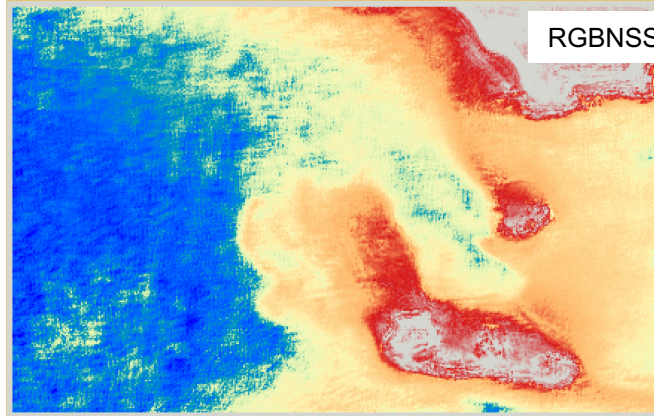
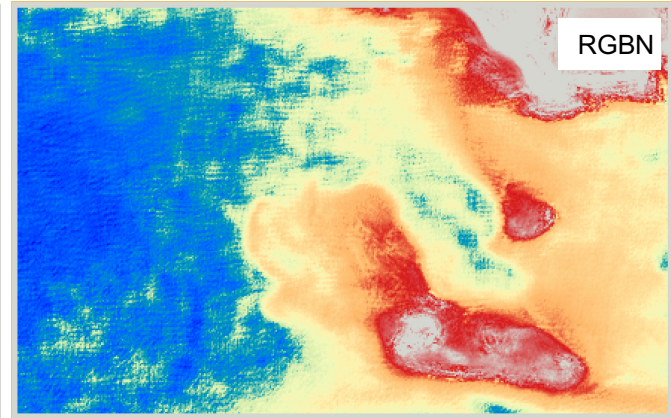
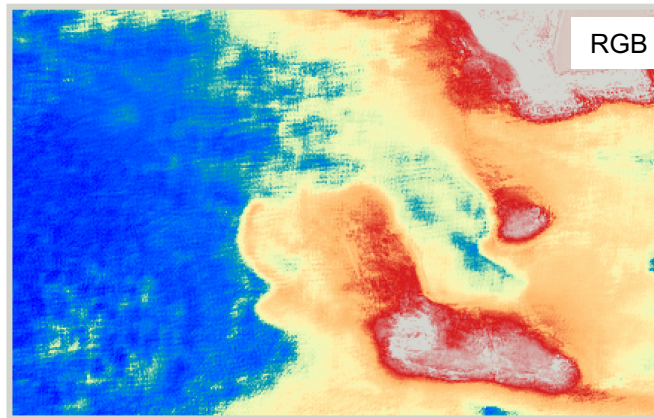


Linear transform

Prediction vs ground truth

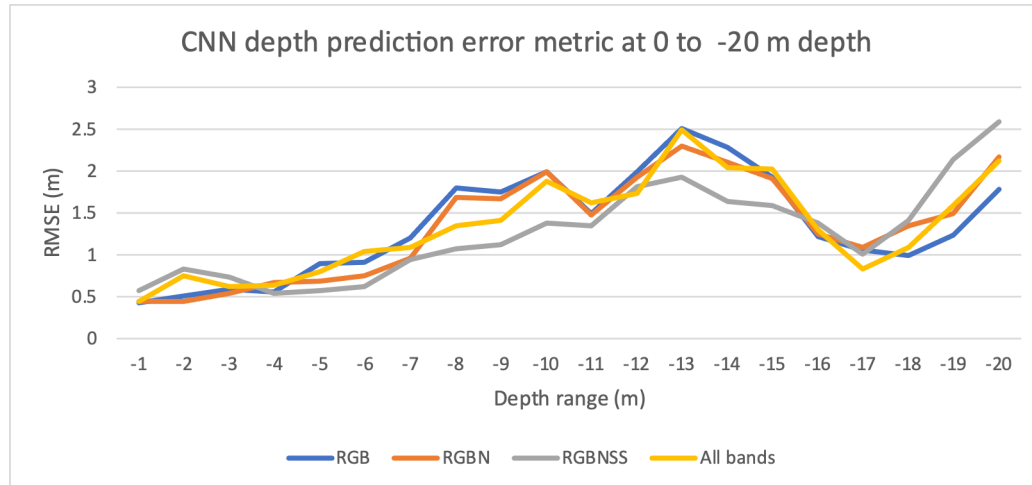


Band combinations

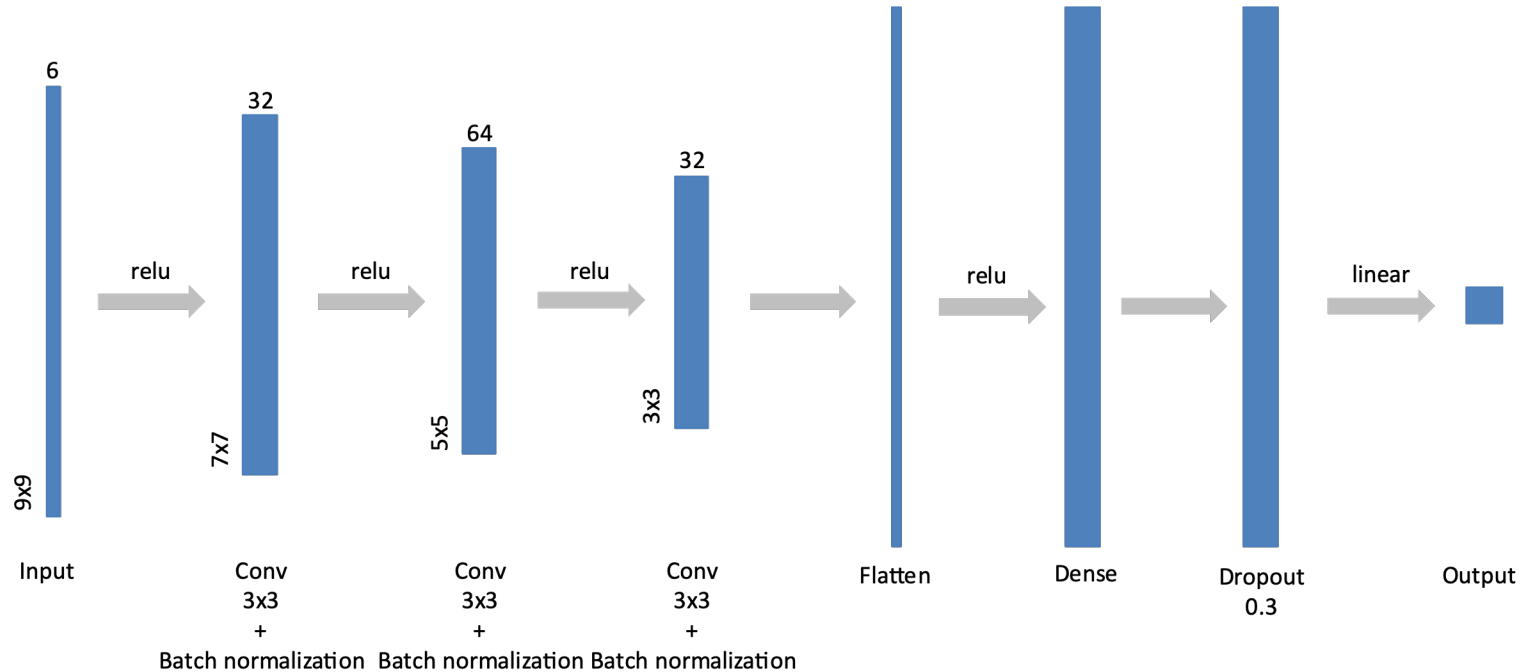


Band combinations

Channels	5x5		7x7		9x9	
	RMSE	R2	RMSE	R2	RMSE	R2
RGB	1.59	0.91	1.53	0.92	1.48	0.94
RGBN	1.64	0.91	1.40	0.93	1.37	0.94
RGBNSS	1.63	0.91	1.53	0.91	1.31	0.94
All bands	1.68	0.90	1.55	0.91	1.45	0.94



Baseline architecture



Experiment #2: SDB comparison in different locations

Setup

Study area

AOI-2, AOI-3, AOI-4

Architecture

CNN3

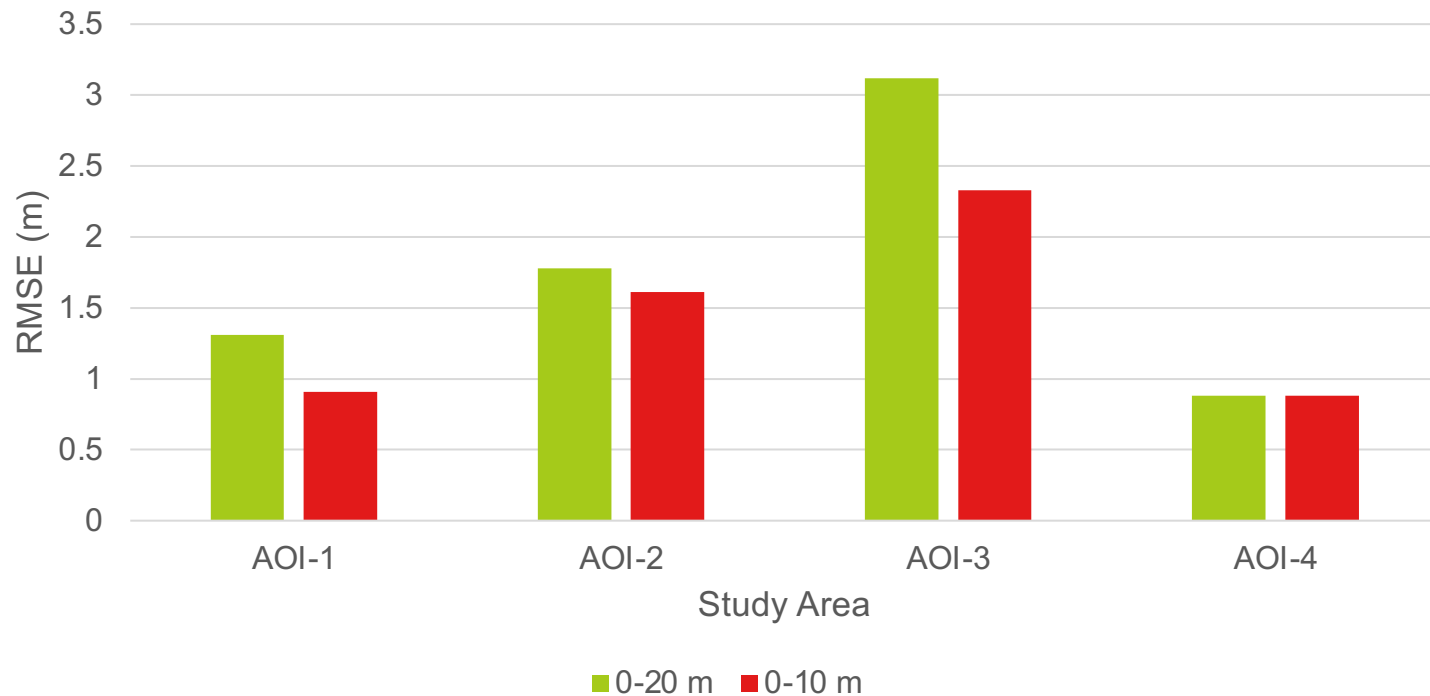
Window size

9x9

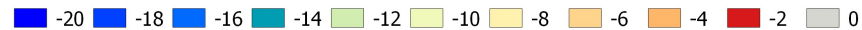
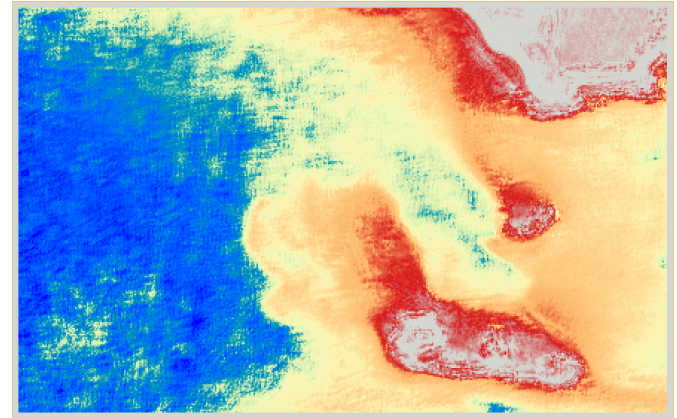
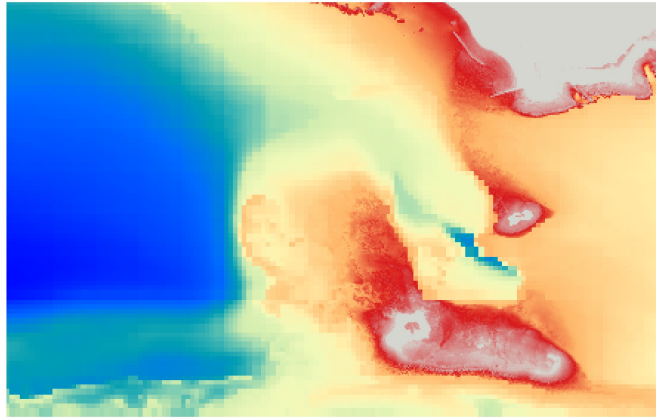
Band combination

RGBNSS

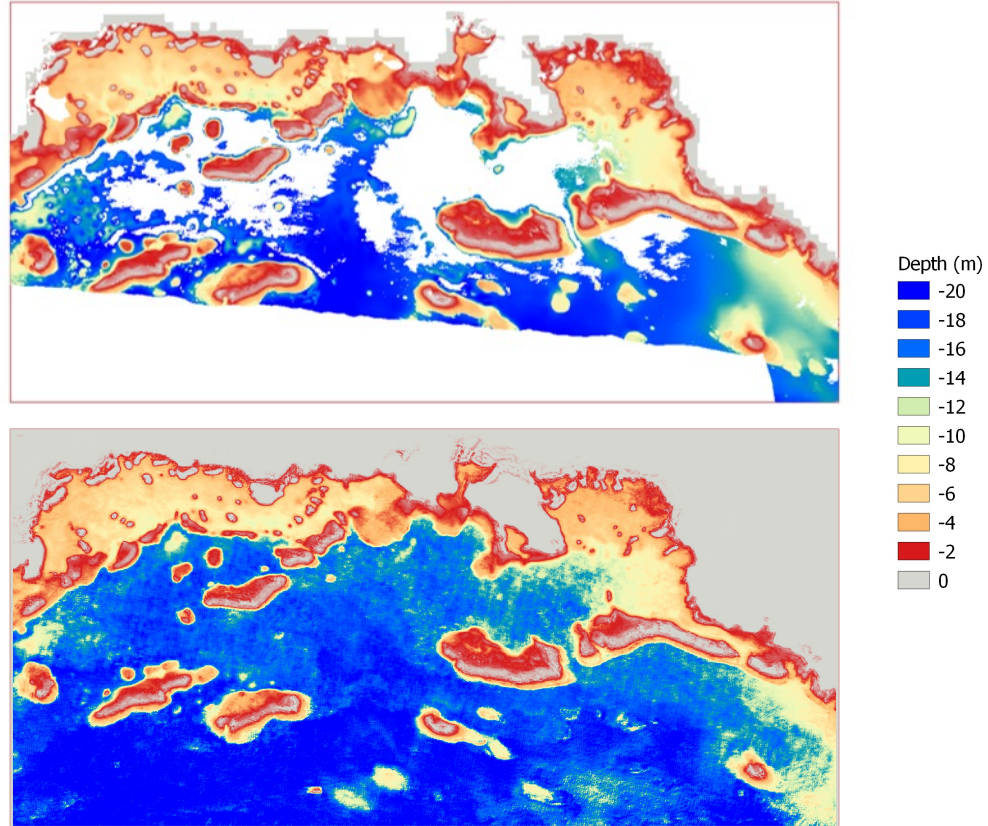
Accuracy



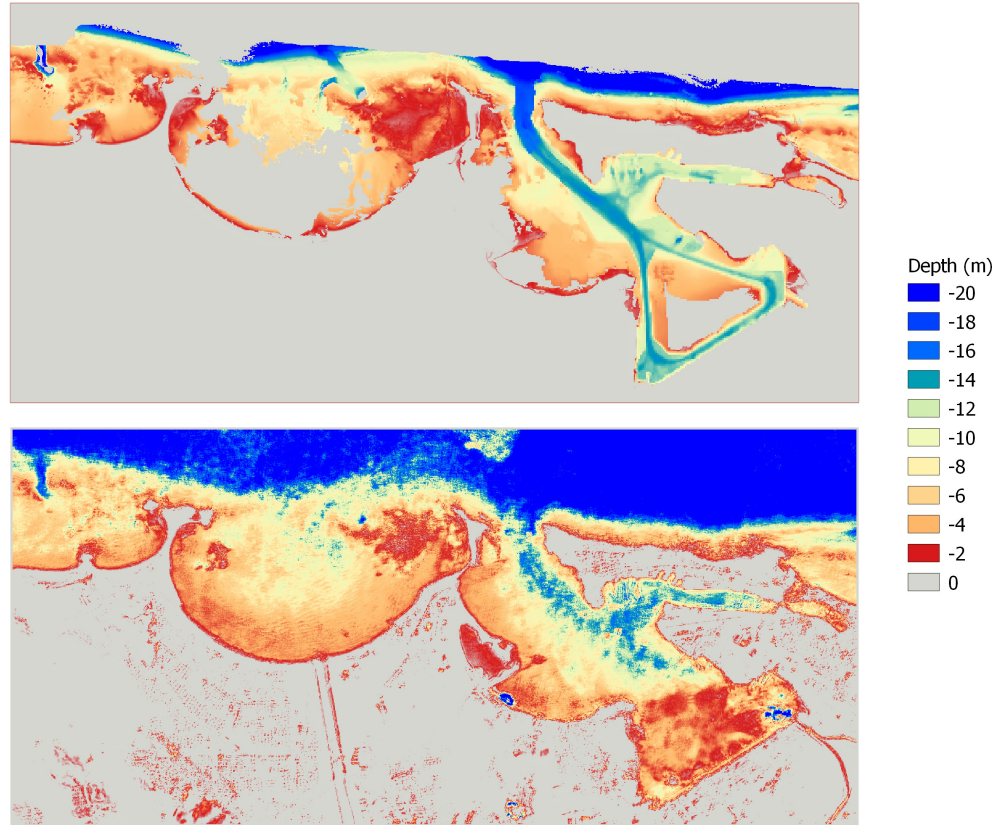
Ground truth vs SDB (AOI-1)



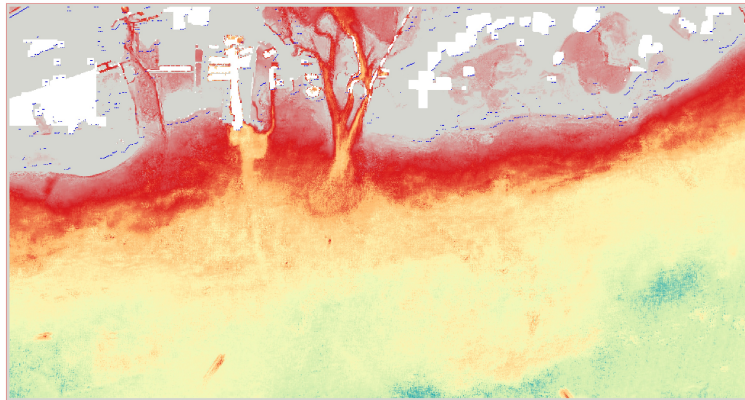
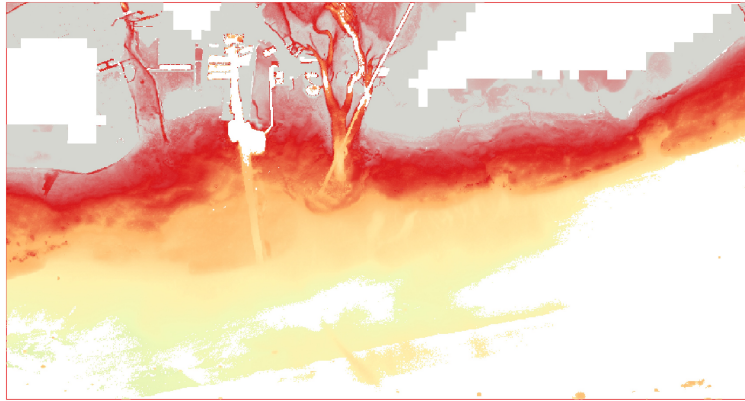
Ground truth vs SDB (AOI-2)



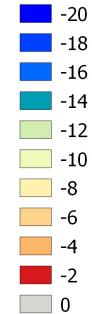
Ground truth vs SDB (AOI-3)



Ground truth vs SDB (AOI-4)



Depth (m)



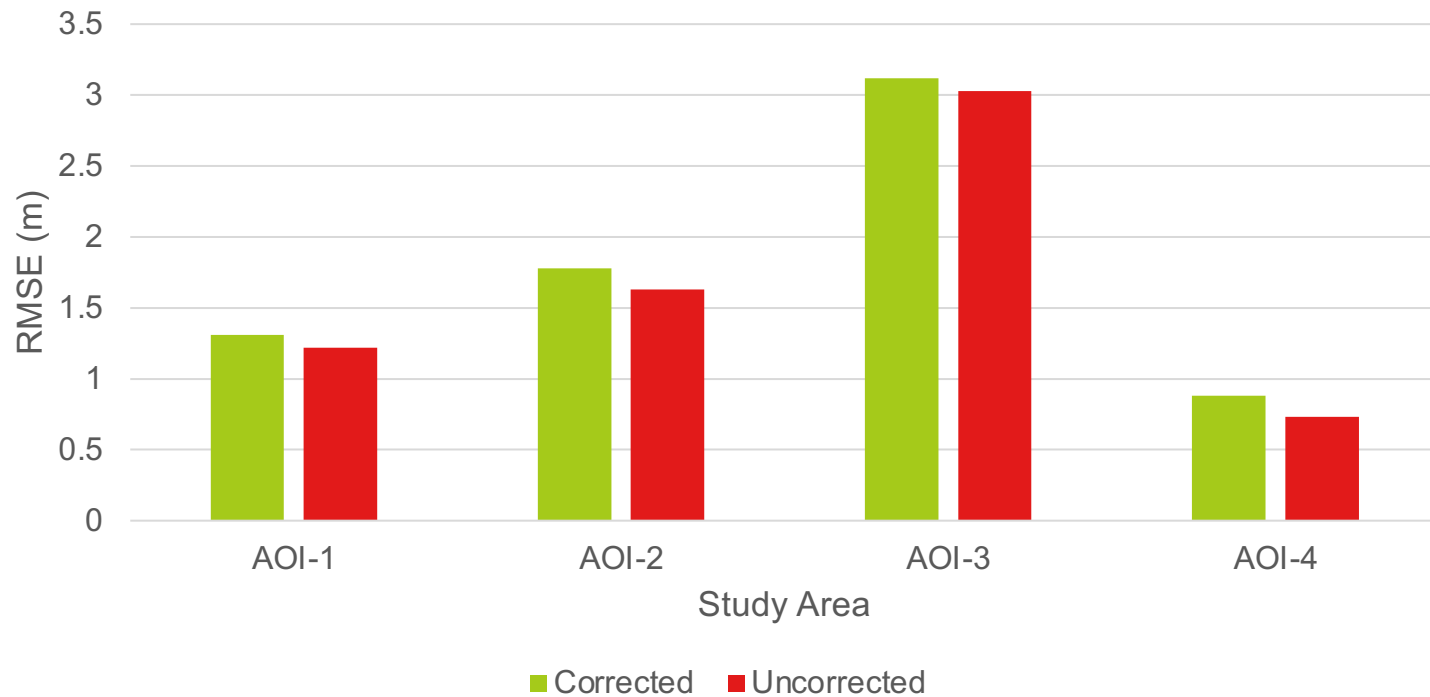
Accuracy (m)	CNN	Ratio Transform
MedAE	0.29	0.39

Experiment #3: SDB using uncorrected images

Motivation

- In some cases, image correction using deep water pixels encounters difficulty due to the large absorption of lights by the molecules in the water column

Accuracy

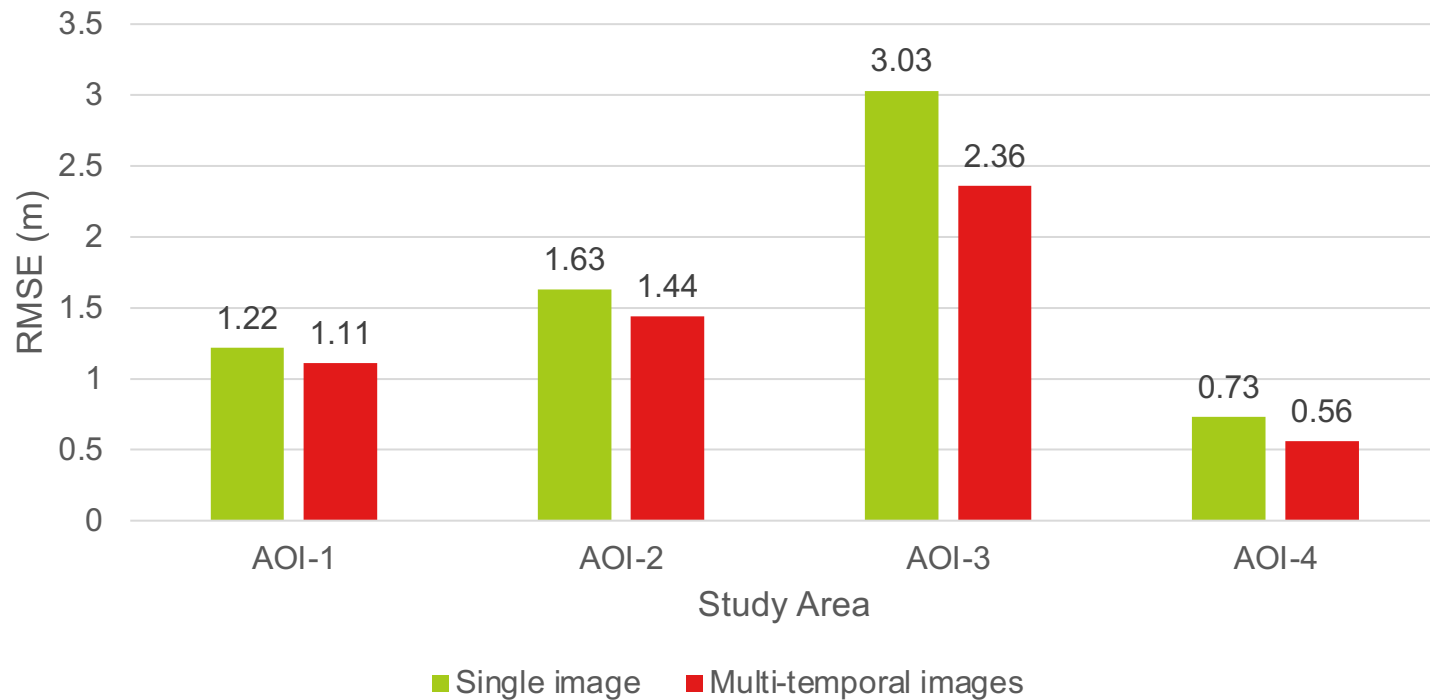


Experiment #4: Multi-temporal images

Setup

Study area	AOI-1, AOI-2, AOI-3, AOI-4
Architecture	CNN3
Window size	9x9
Band combination	RGBNSS
Image collection	2019

Accuracy



Experiment #5: Transfer model

Setup

Study area

AOI-5, AOI-6

Architecture

CNN3

Window size

9x9

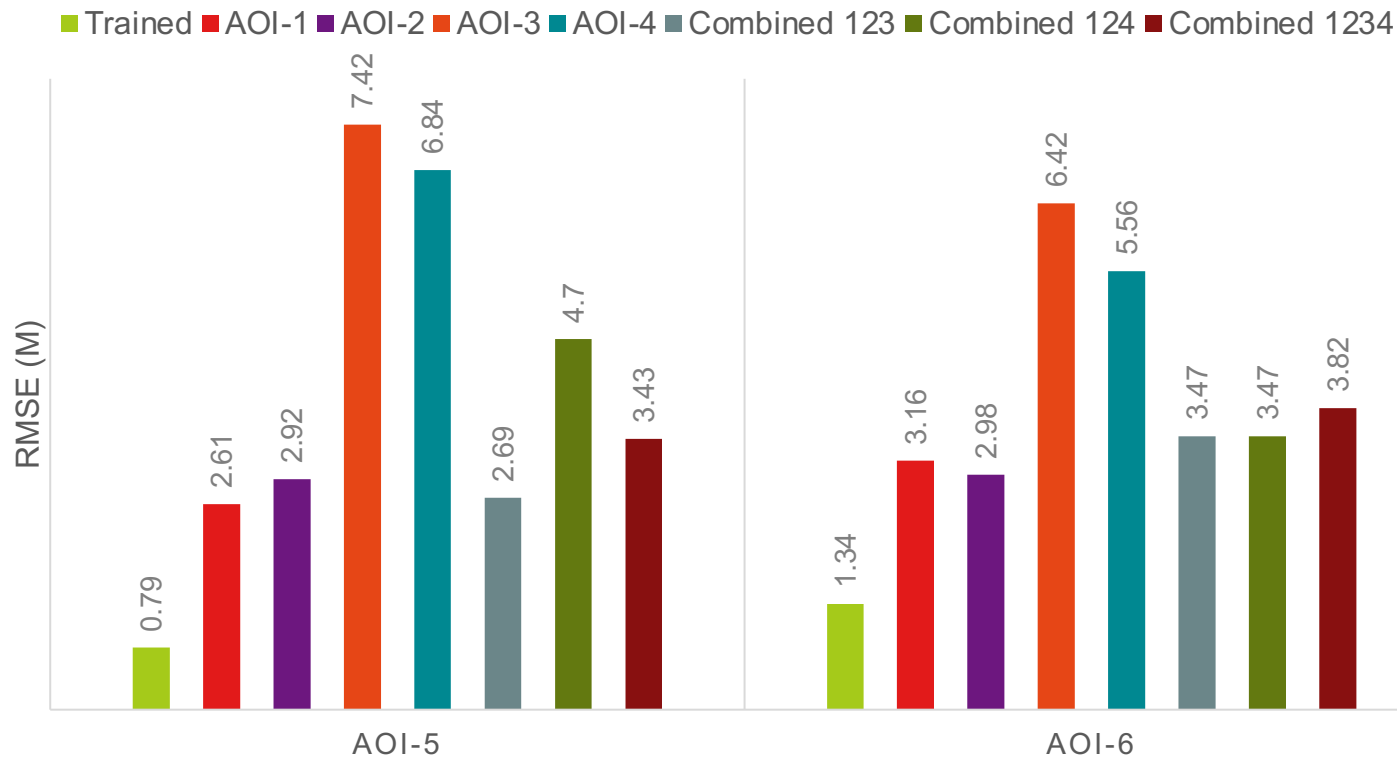
Band combination

RGBNSS

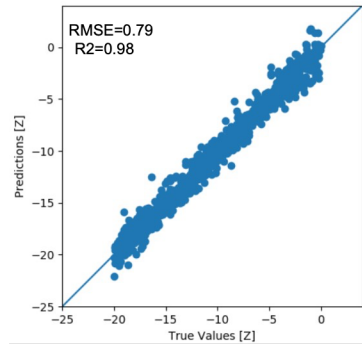
Accuracy (AOI-5 & AOI-6)

RMSE (m)	CNN	Other methods	
AOI-5	0.79	1.24	Random Forest
AOI-6	1.34	3.01	Radiative transfer

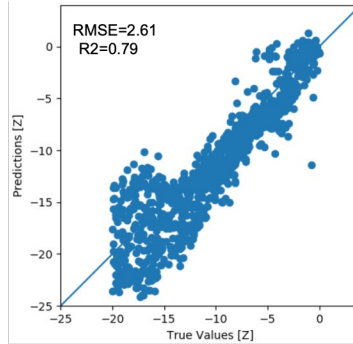
Accuracy



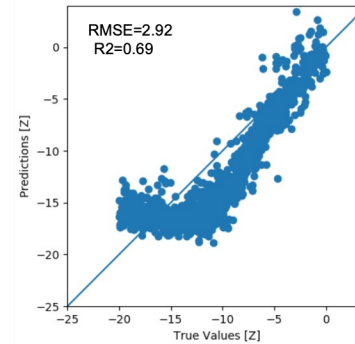
Prediction vs ground truth AOI-5



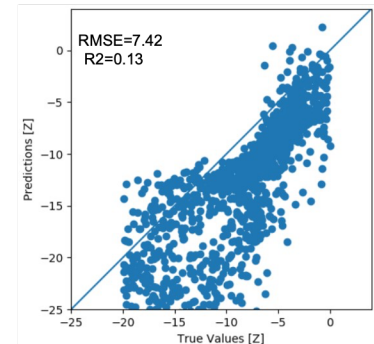
a) Trained



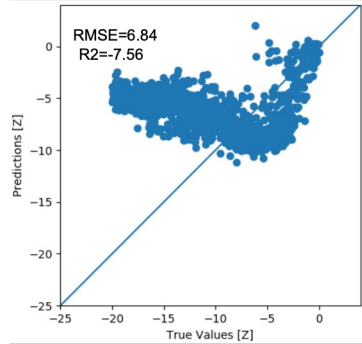
b) Pretrained on AOI-1



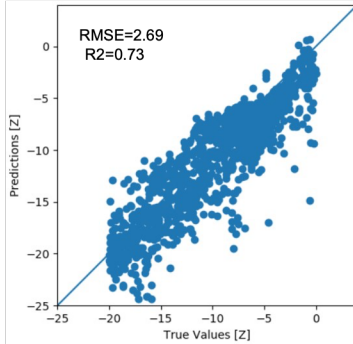
c) Pretrained on AOI-2



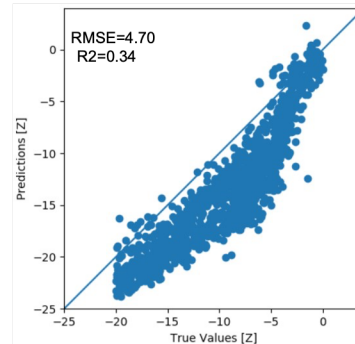
d) Pretrained on AOI-3



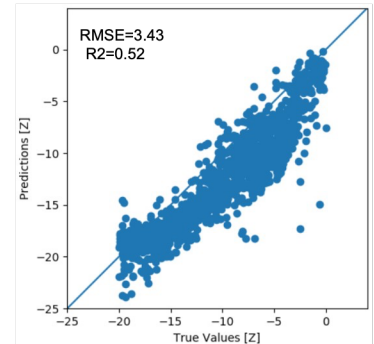
e) Pretrained on AOI-4



f) Pretrained on AOI-1+2+3

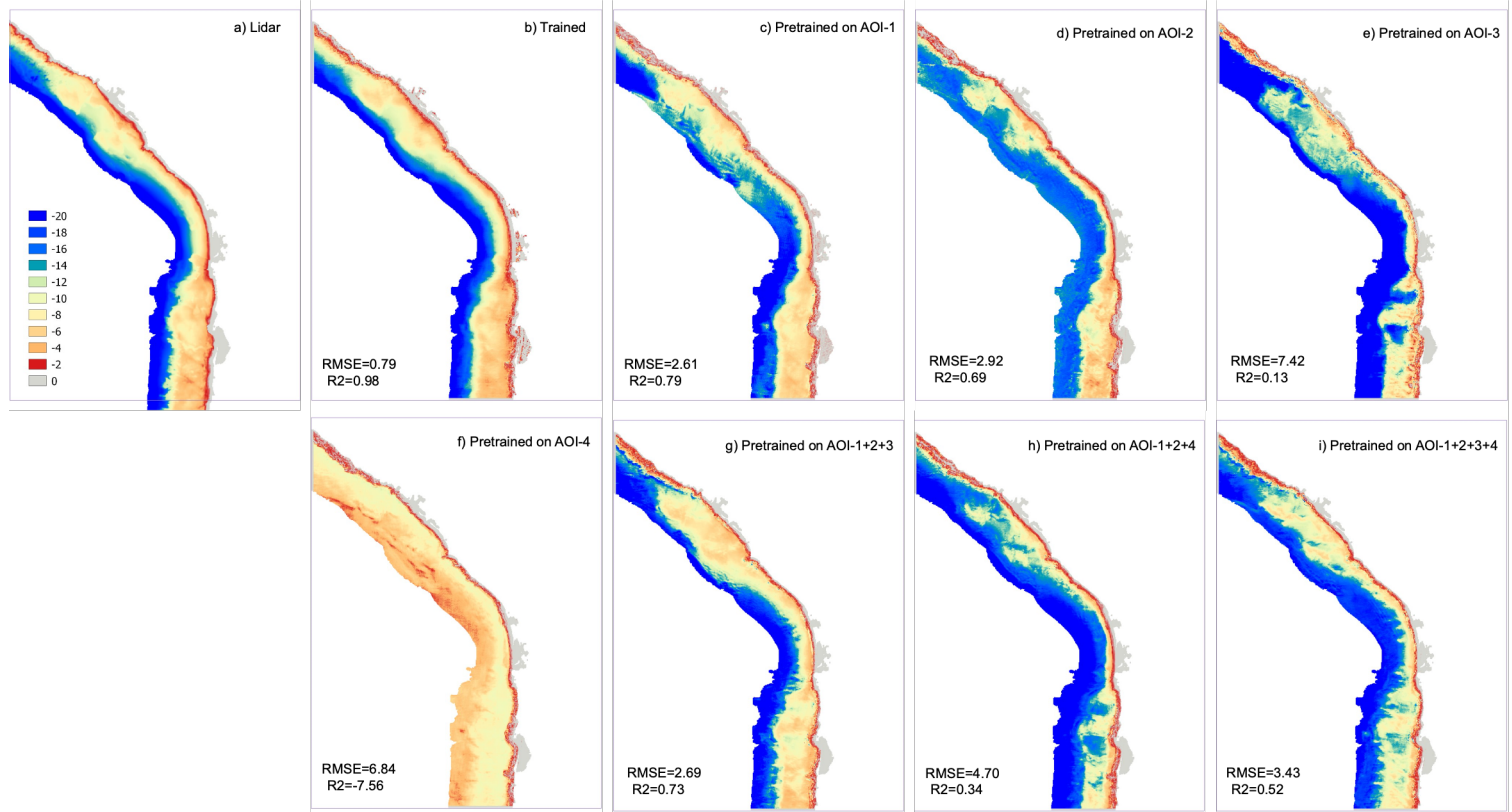


g) Pretrained on AOI-1+2+4

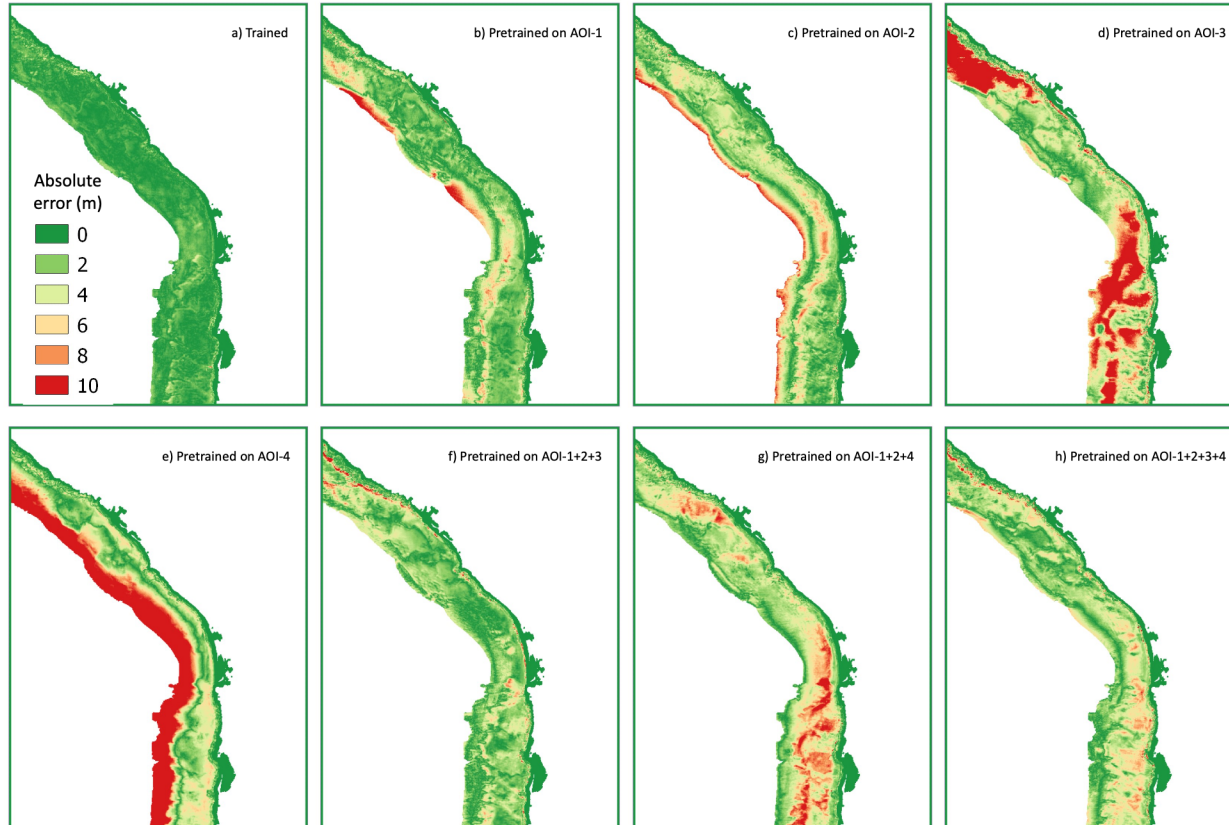


h) Pretrained on AOI-1+2+3+4

SDB AOI-5



Error map AOI-5



Experiment #6: SDB production in a larger area

Setup

Study area

Oahu island

Architecture

CNN3

Window size

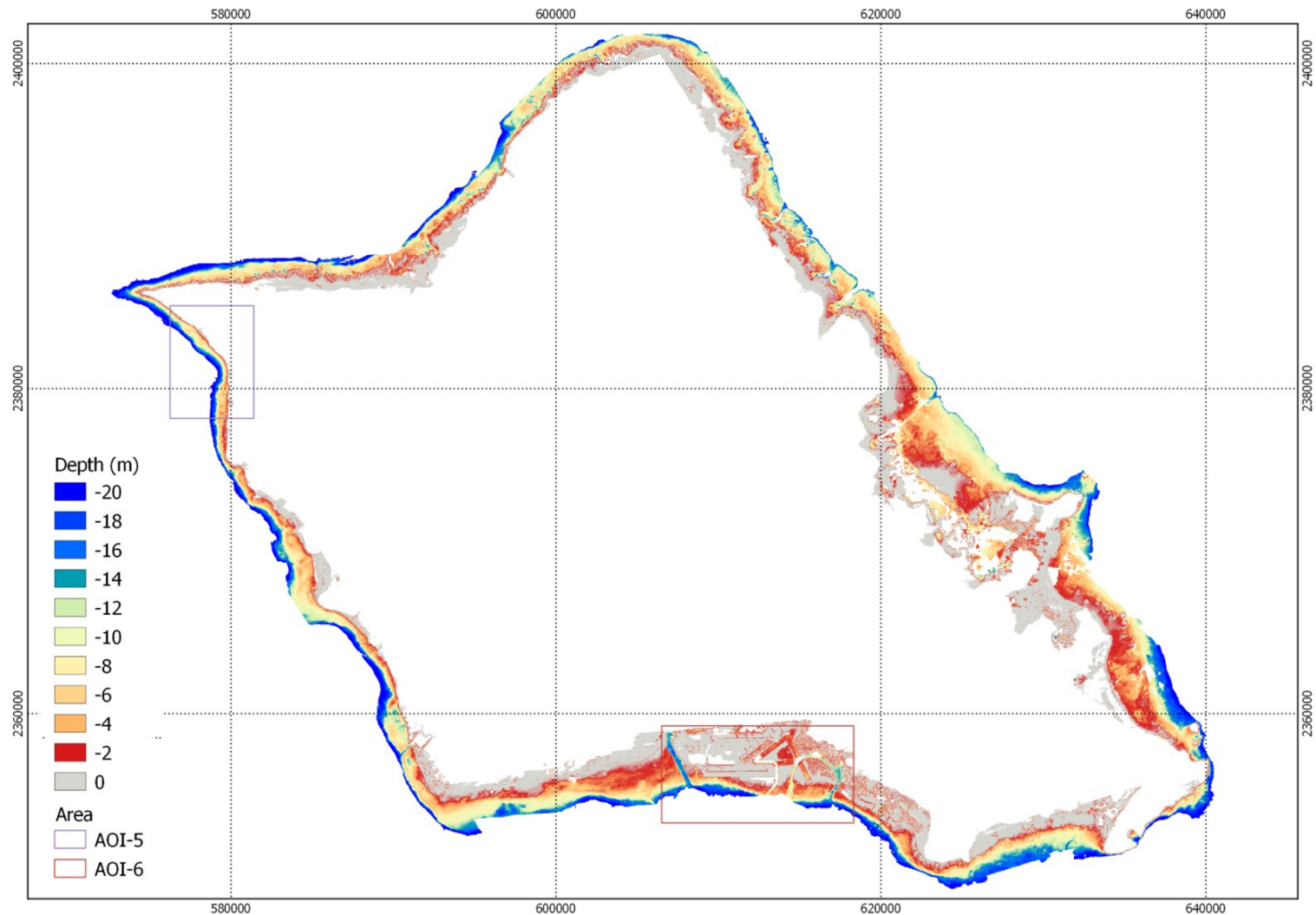
9x9

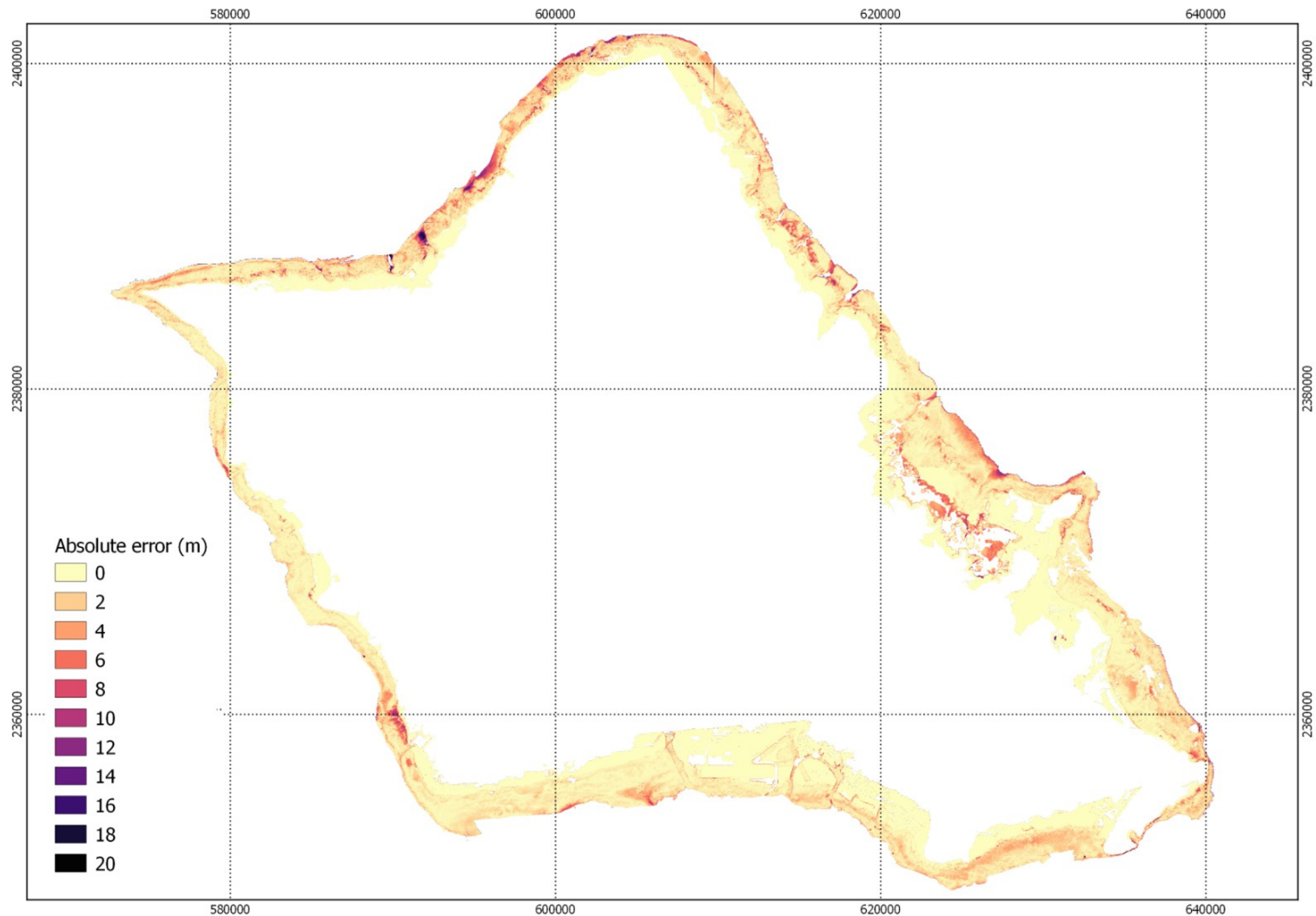
Band combination

RGBNSS

Training data

AOI-5 + AOI-6



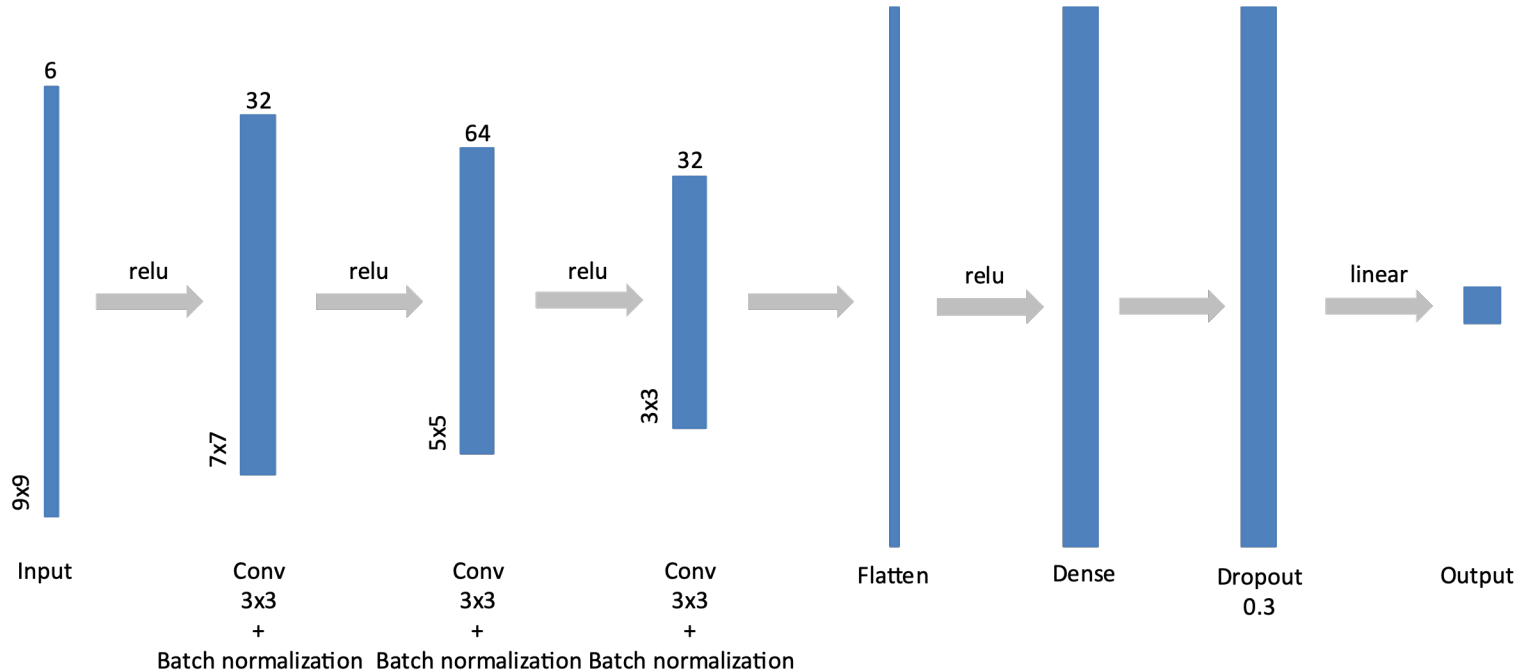


Conclusions

What kind of preprocessing is needed for the data sets?

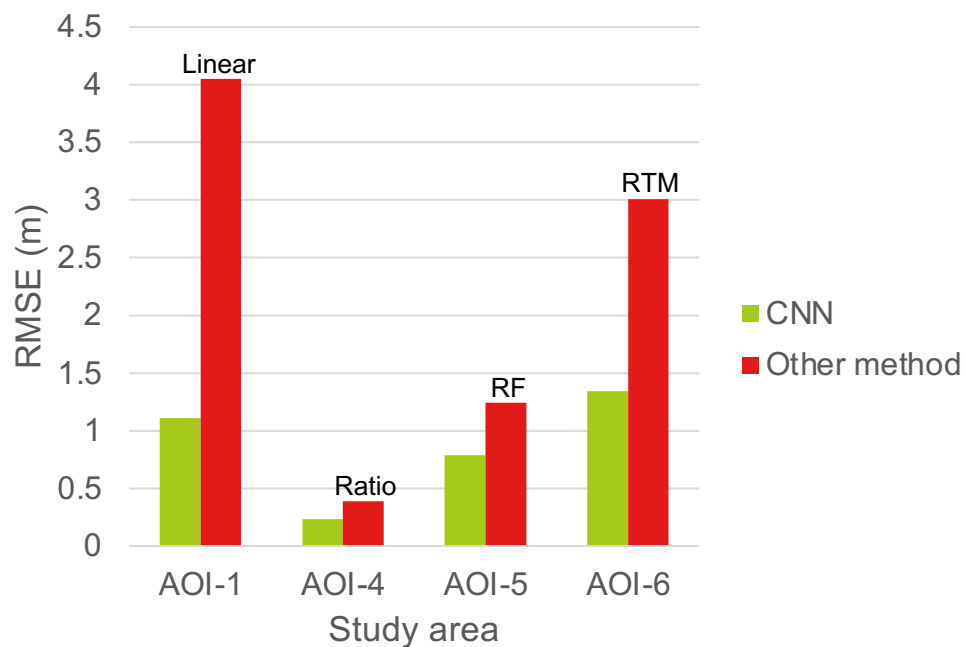
- **No additional preprocessing is required**

What kind of CNN architecture can be used for SDB?



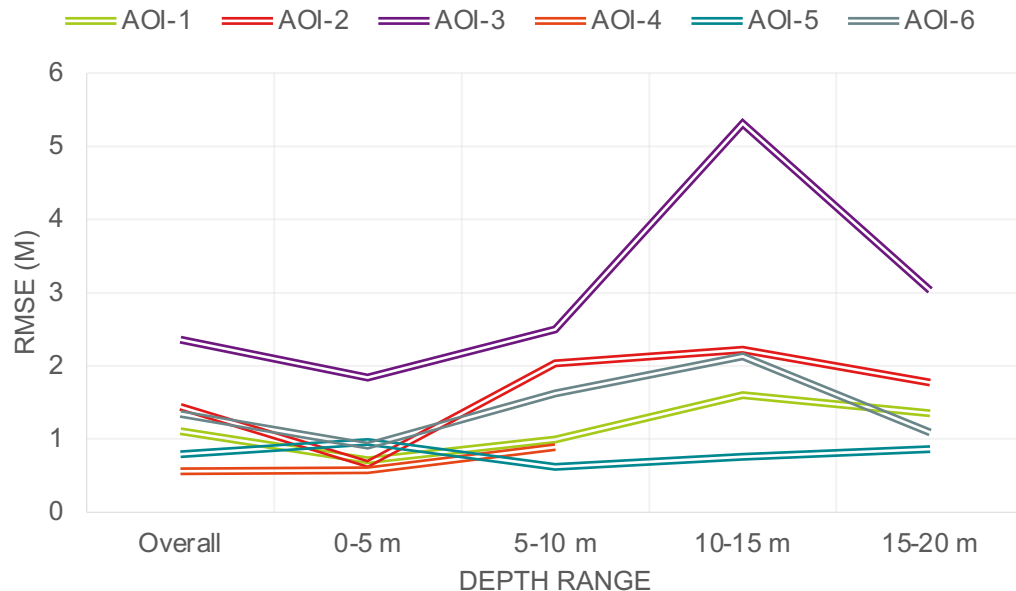
What is the accuracy of the method?

- Compared to other methods



What is the accuracy of the method?

- In different depth ranges and locations



To what extent can the pretrained model be reused?

- Should consider coastal water characteristics
- Combining multiple training data in different locations increase the variety, but need to balance the distribution
- Still need ground truth data to assess the accuracy

Future work

Balancing the training data

Verification using another data source

SDB in the colder water and freshwater

Thank you