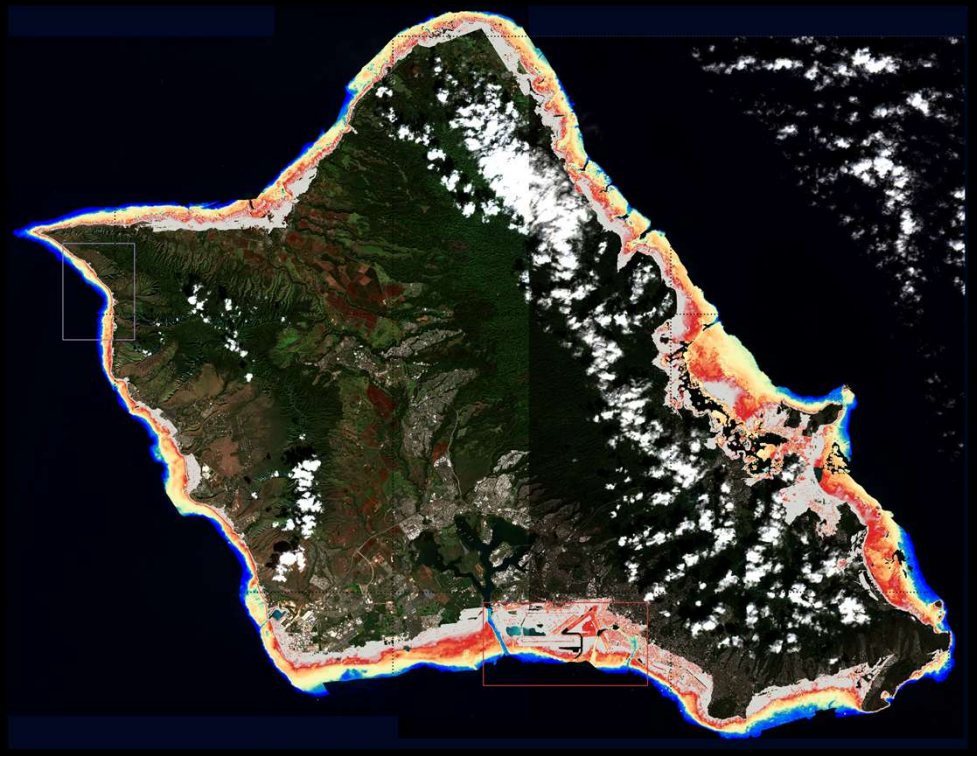
Convolutional Neural Networks for Satellite-Derived Bathymetry



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Outline

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

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Introduction

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What is bathymetry?

Study of the water beds

Bathymetry surveys reveal the terrain of water bed

Essential for coastal management and research

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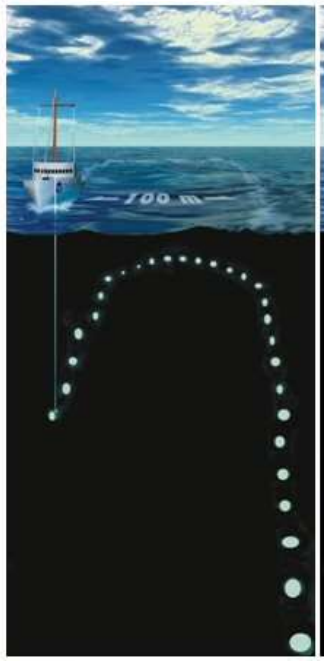
How to get bathymetry data?

Leadline

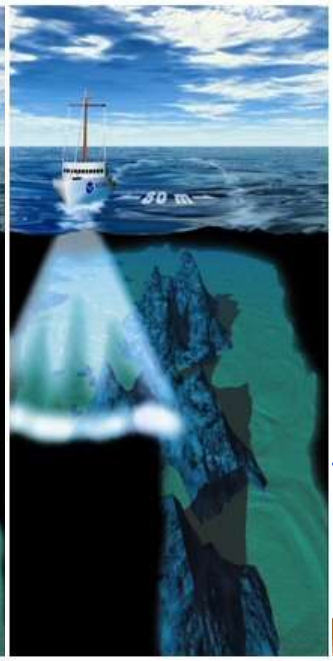


NOAA, 2016

SBES

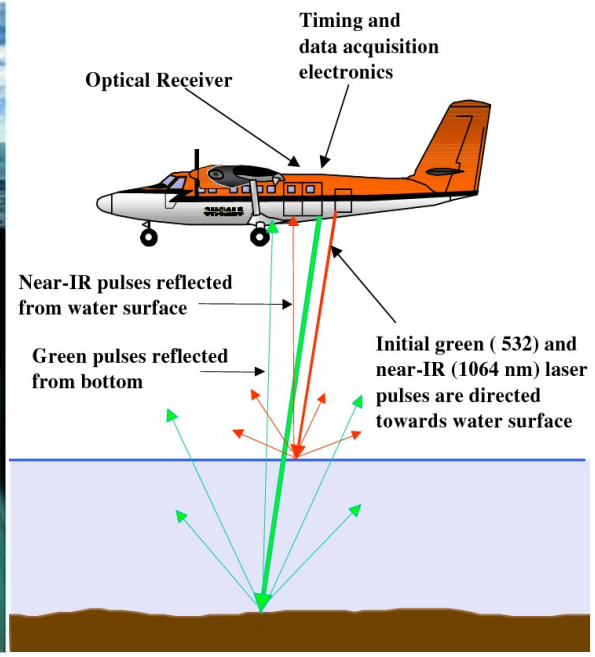
NOAA, 2016

MBES



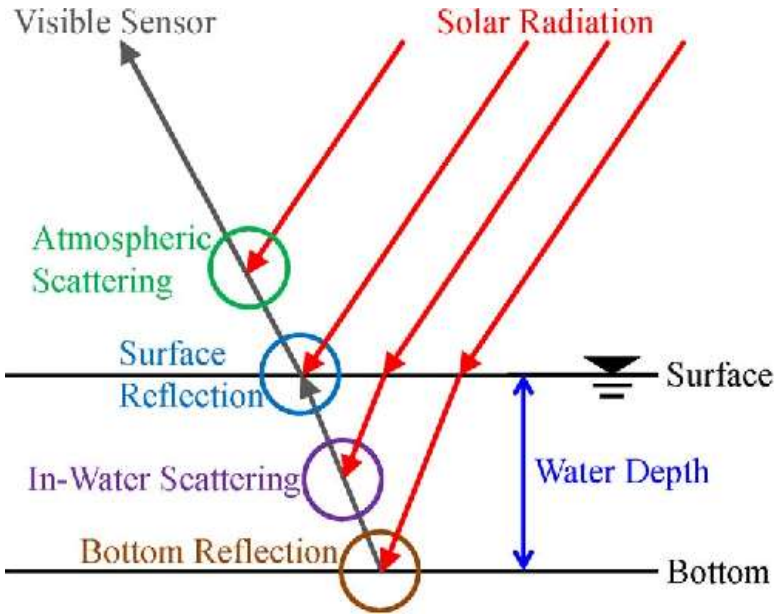
NOAA, 2016

LiDAR



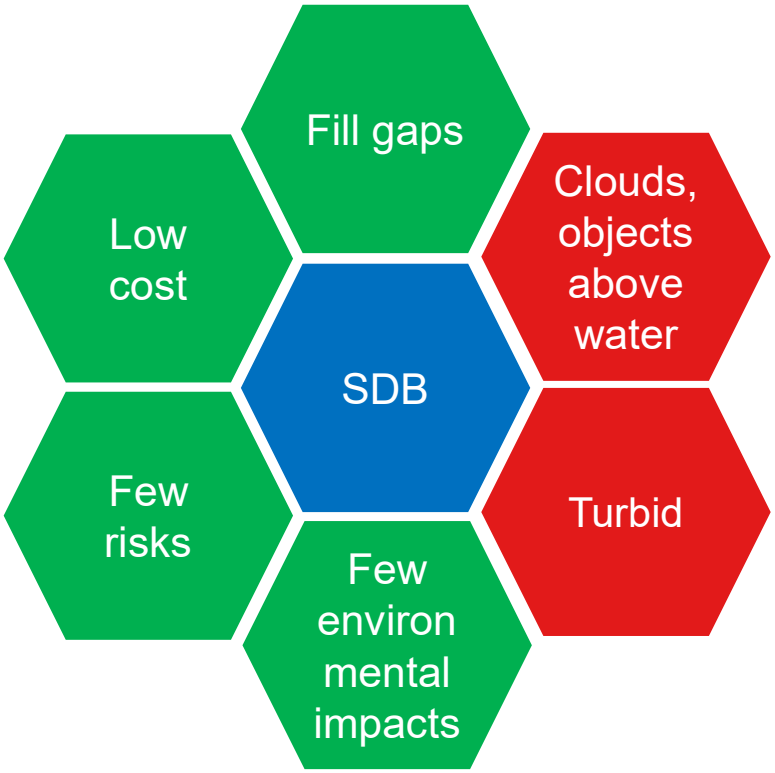
LaRocque and West, 1999

Satellite-Derived Bathymetry



Kanno et al., 2012

Why SDB?



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Related work

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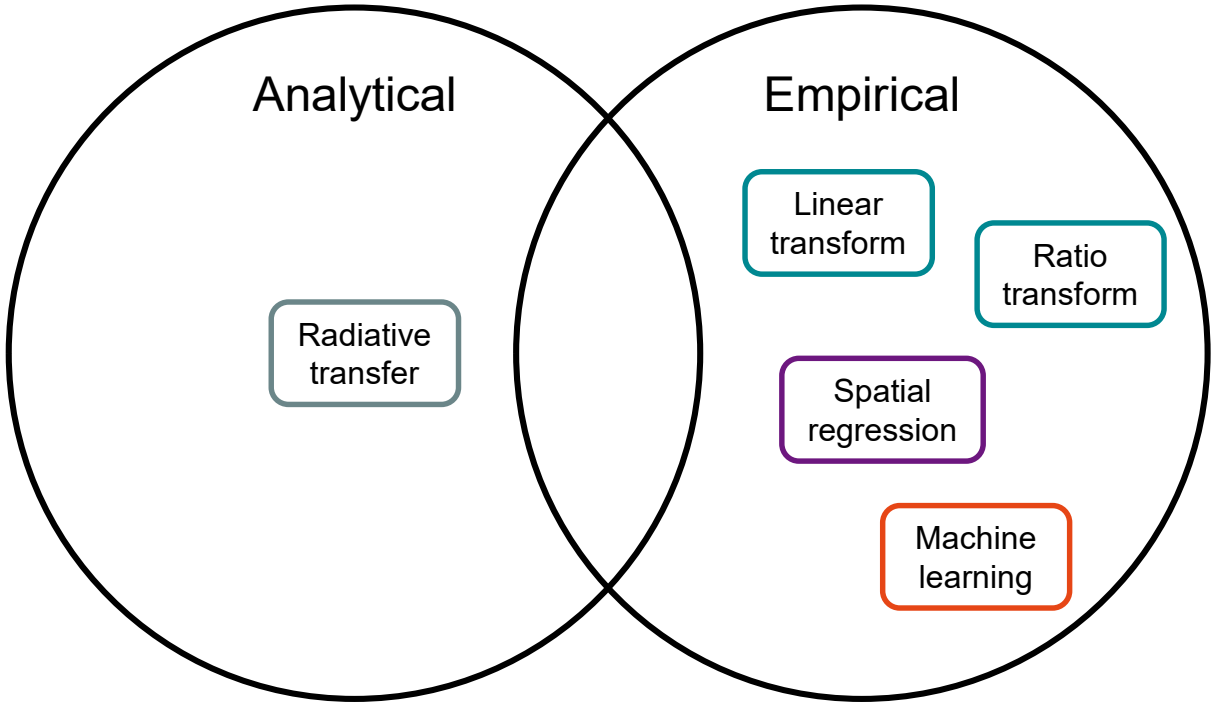
SDB methods



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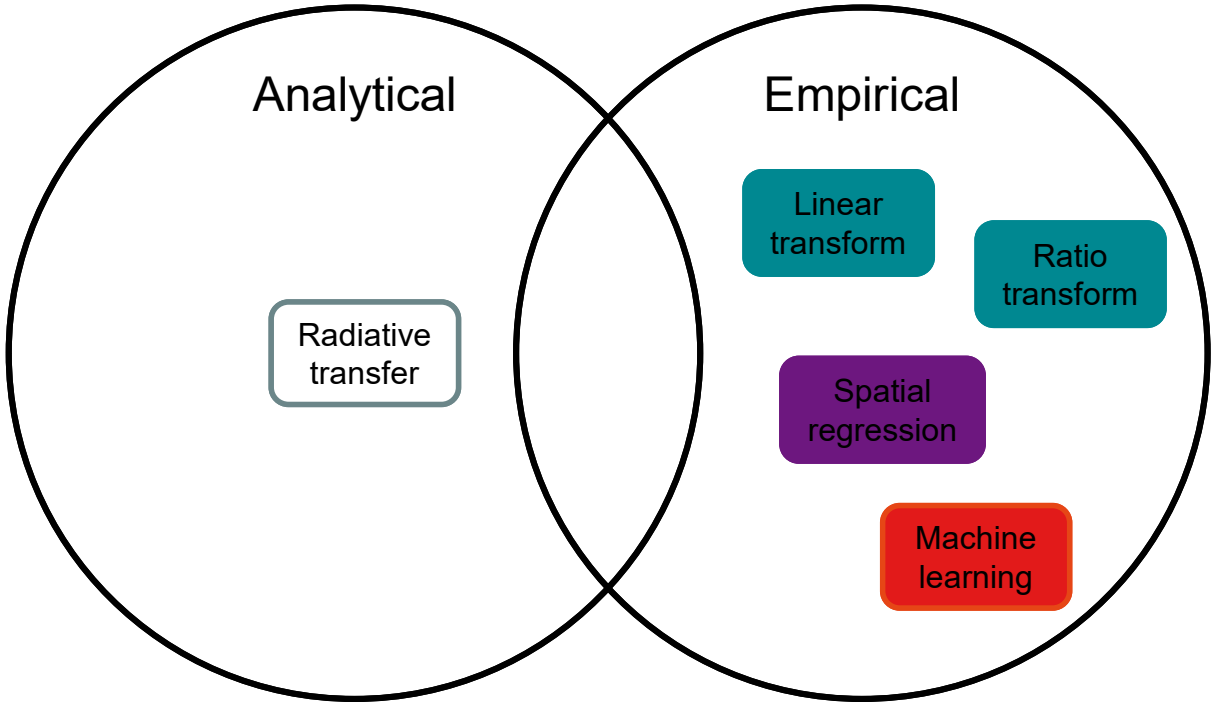
SDB methods



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Factors to consider

- Nonlinearity due to bottom types/noise
- Spatial correlation

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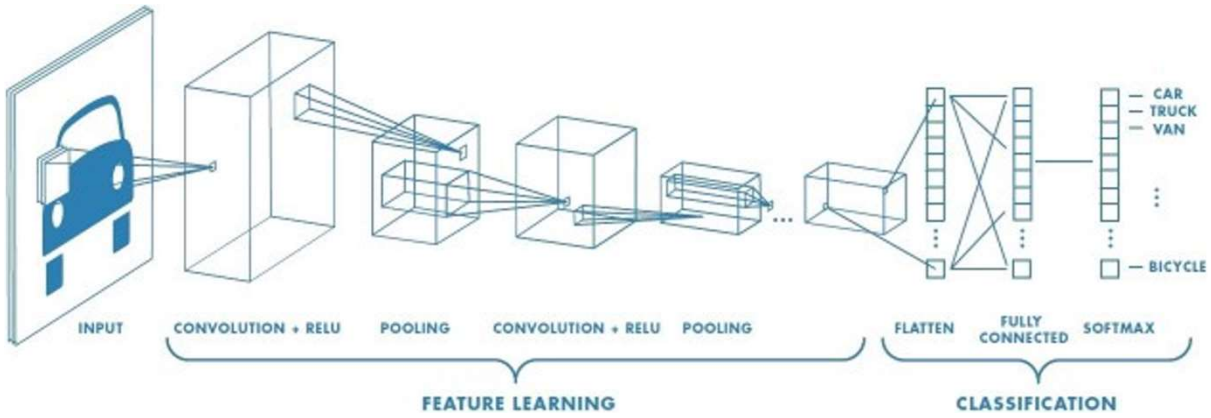
Convolutional Neural Networks



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Research objective

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

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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?

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Methodology

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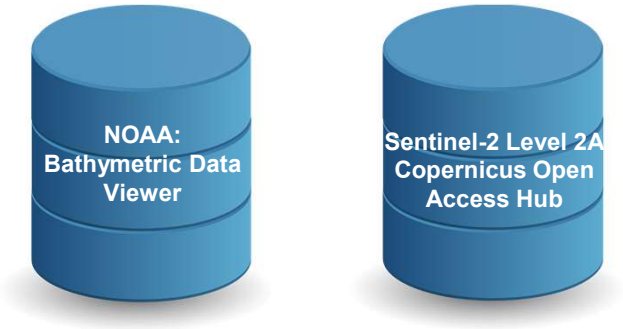
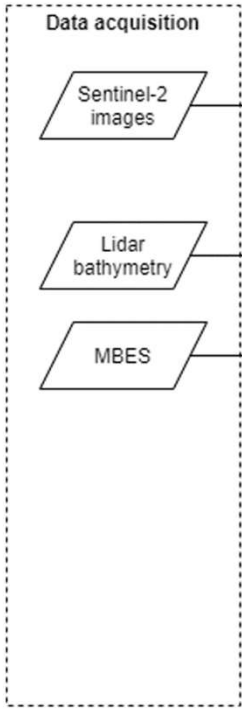
Study areas

- Puerto Rico
- Key West
- Hawaii

Data


NOAA:
Bathymetric Data
Viewer
Sentinel-2 Level 2A
Copernicus Open
Access Hub

Workflow



Workflow

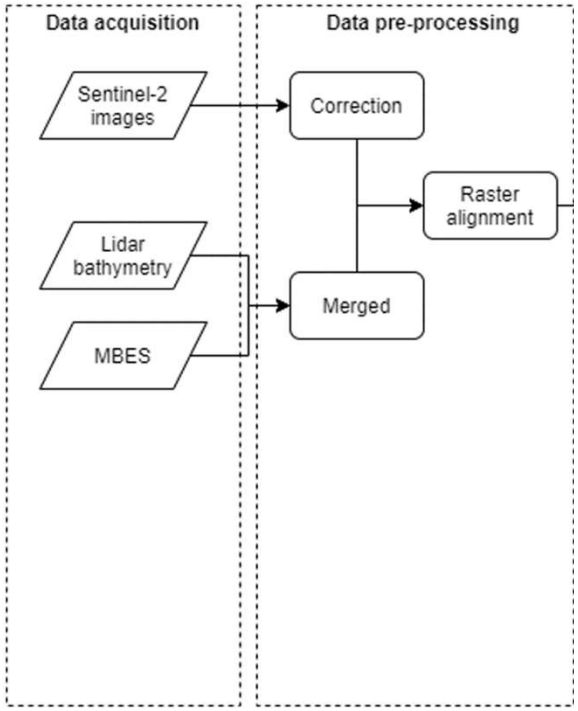
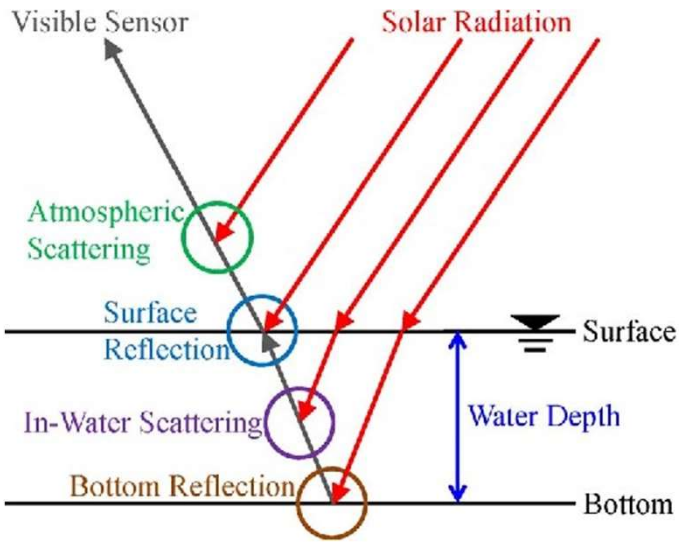
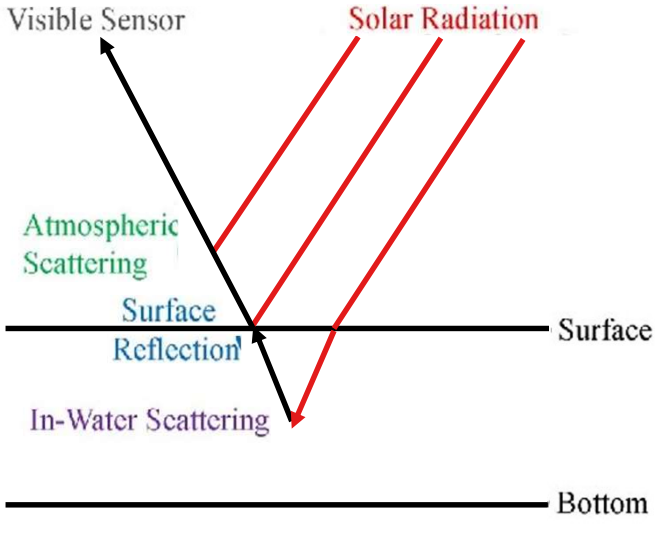

Data acquisition
Data pre-processing
Sentinel-2 images
Lidar bathymetry
MBES
Correction
Raster alignment
Merged

Image correction

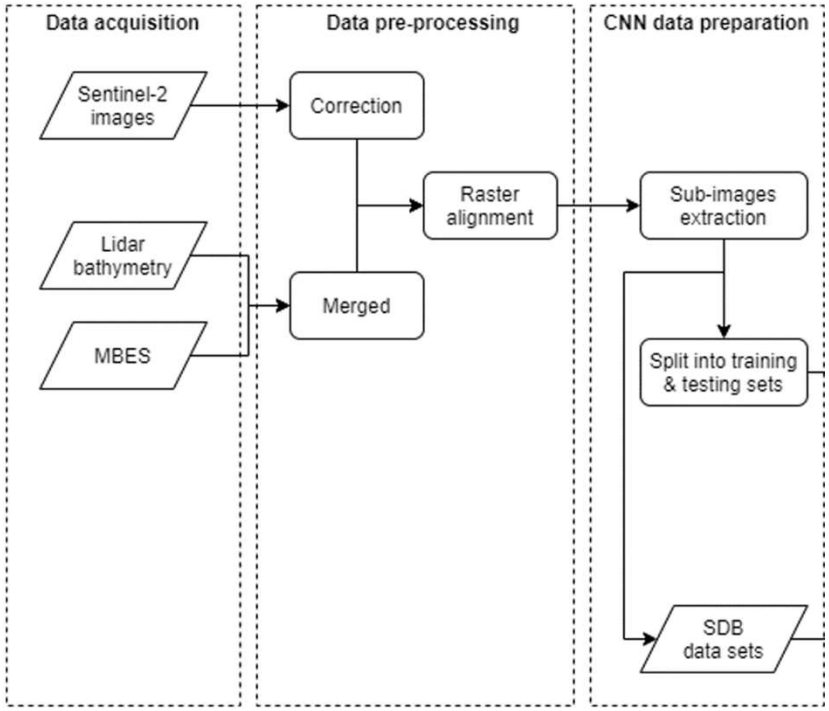


Shallow water

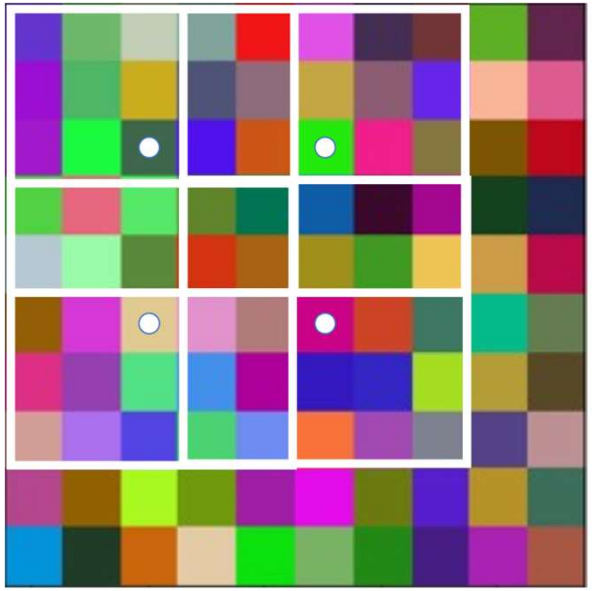


Deep water

Workflow


Data acquisition
Data pre-processing
CNN data preparation
Sentinel-2 images
Lidar bathymetry
MBES
Correction
Raster alignment
Merged
Sub-images extraction
Split into training & testing sets
SDB data sets

Sub-images extraction



Sub-images for training and testing

Sub-images for SDB model generation

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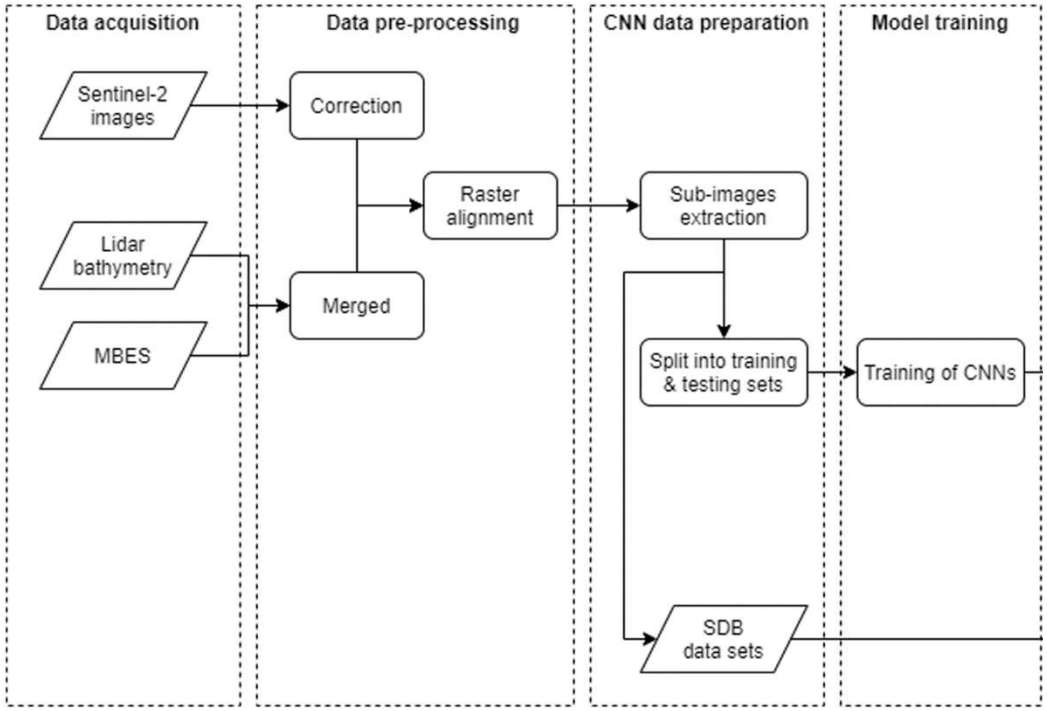
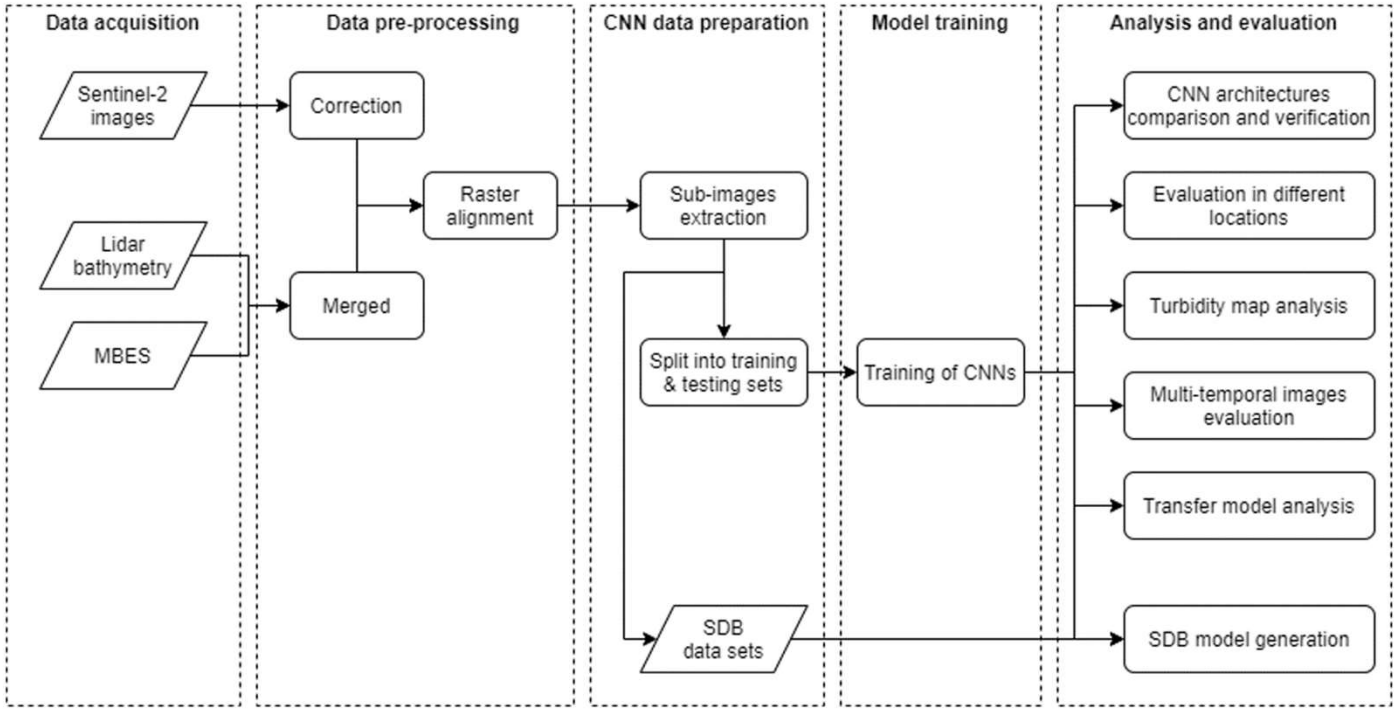
Workflow


Data acquisition
Data pre-processing
CNN data preparation
Model training
Sentinel-2 images
Lidar bathymetry
MBES
Correction
Raster alignment
Merged
Sub-images extraction
Split into training & testing sets
SDB data sets
Training of CNNs

Workflow


Data acquisition
Data pre-processing
CNN data preparation
Model training
Analysis and evaluation
Sentinel-2 images
Lidar bathymetry
MBES
Correction
Raster alignment
Merged
Sub-images extraction
Split into training & testing sets
SDB data sets
Training of CNNs
CNN architectures comparison and verification
Evaluation in different locations
Turbidity map analysis
Multi-temporal images evaluation
Transfer model analysis
SDB model generation

Experiment #1: CNN architectures comparison and verification

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Setup

Study area: AOI-1

CNN architecture:

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

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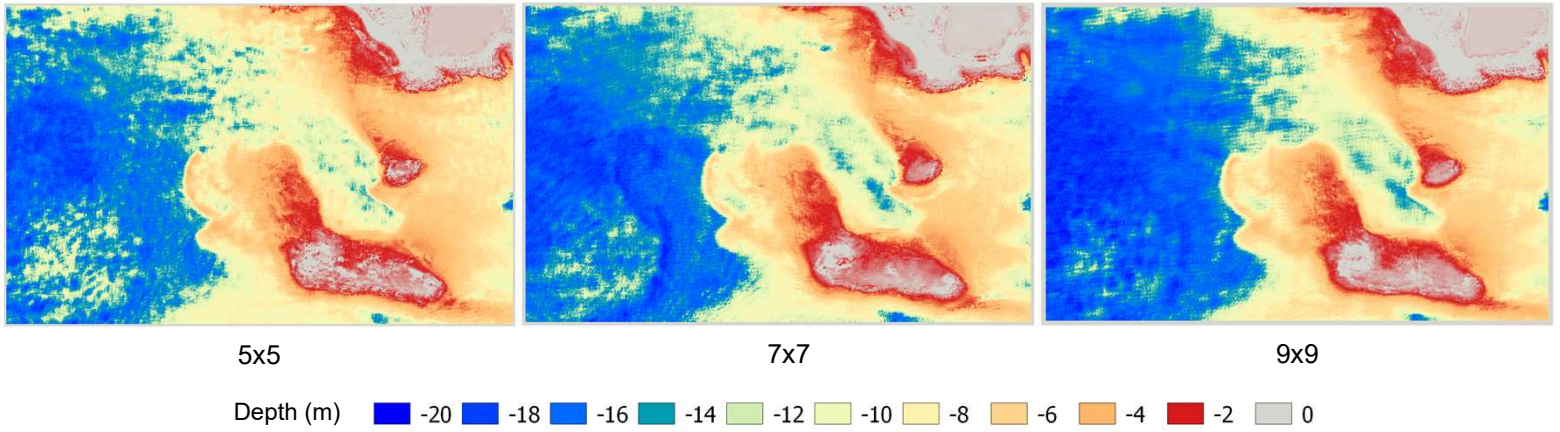
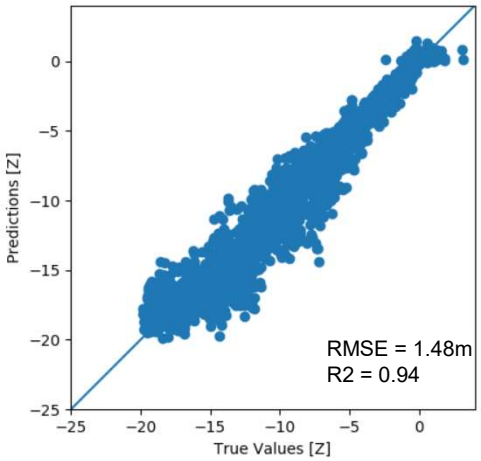
Window sizes

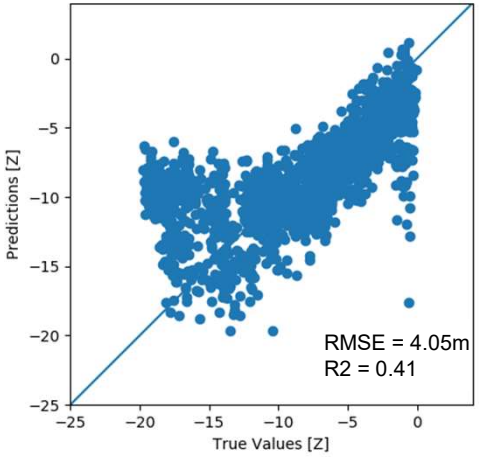
Models	5x5		7x7		9x9	
	RMSE	R2	RMSE	R2	RMSE	R2
CNN1	1.59	0.91	1.58	0.92	1.55	0.93
CNN2	1.94	0.89	1.63	0.91	1.55	0.93
CNN3			1.53	0.92	1.48	0.94
CNN4					1.64	0.90



Comparison to the linear transform

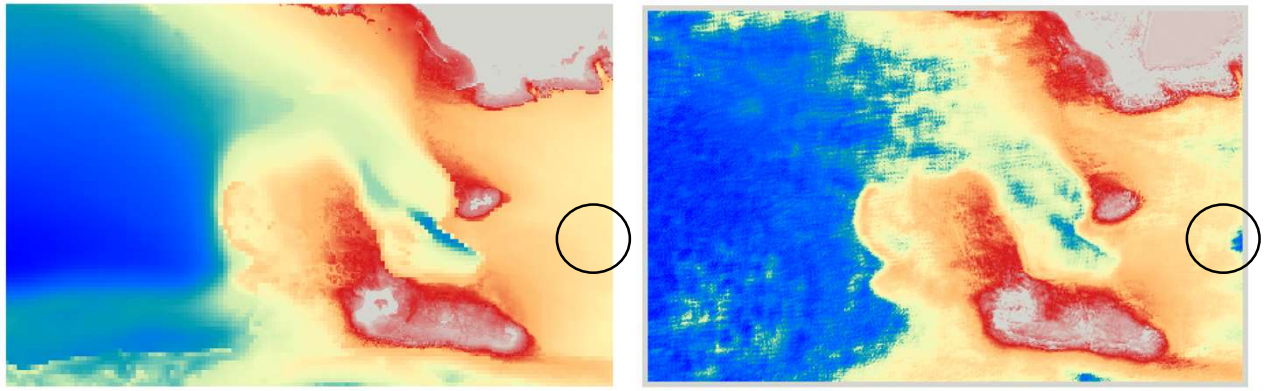


CNN

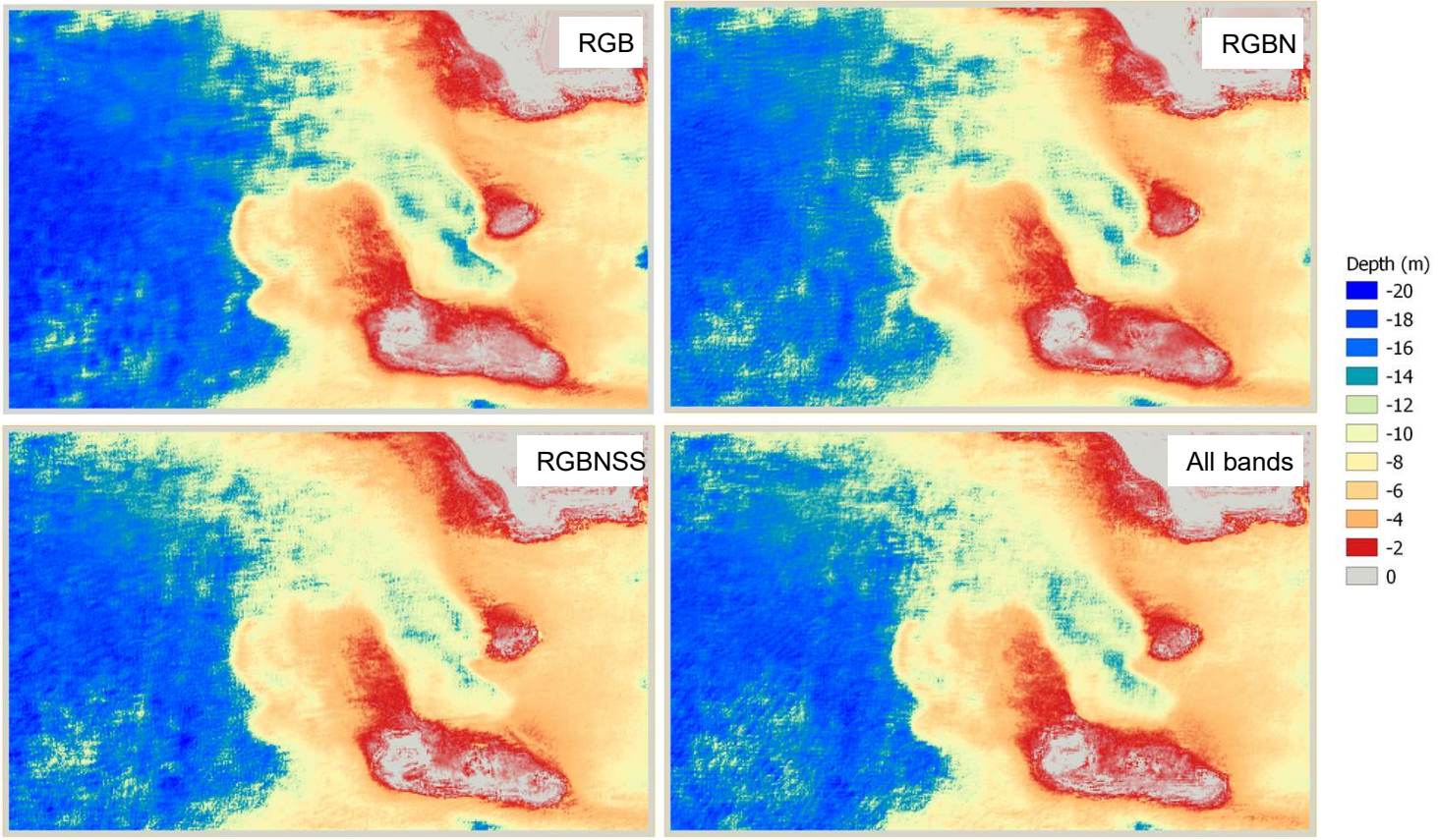


Linear transform

Prediction vs ground truth

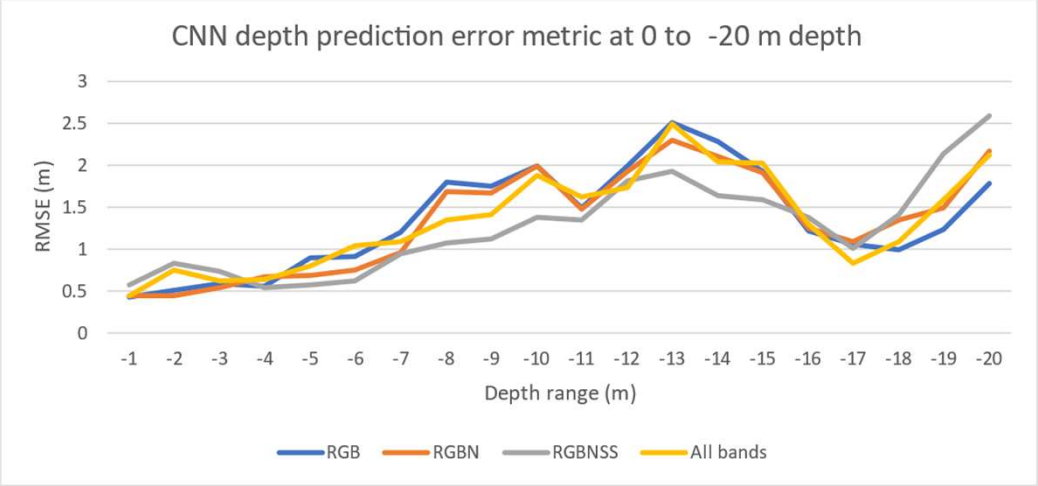


Band combinations

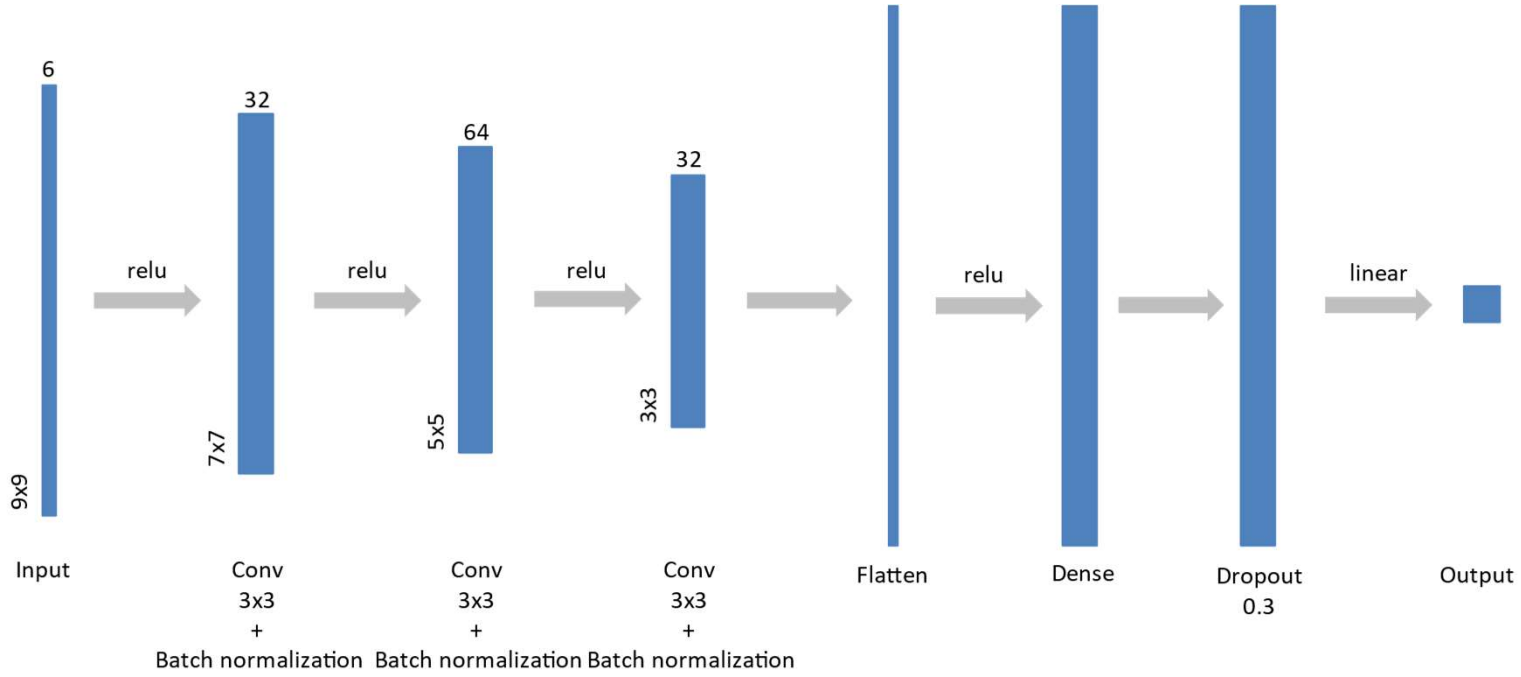


Band combinations

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

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Setup

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

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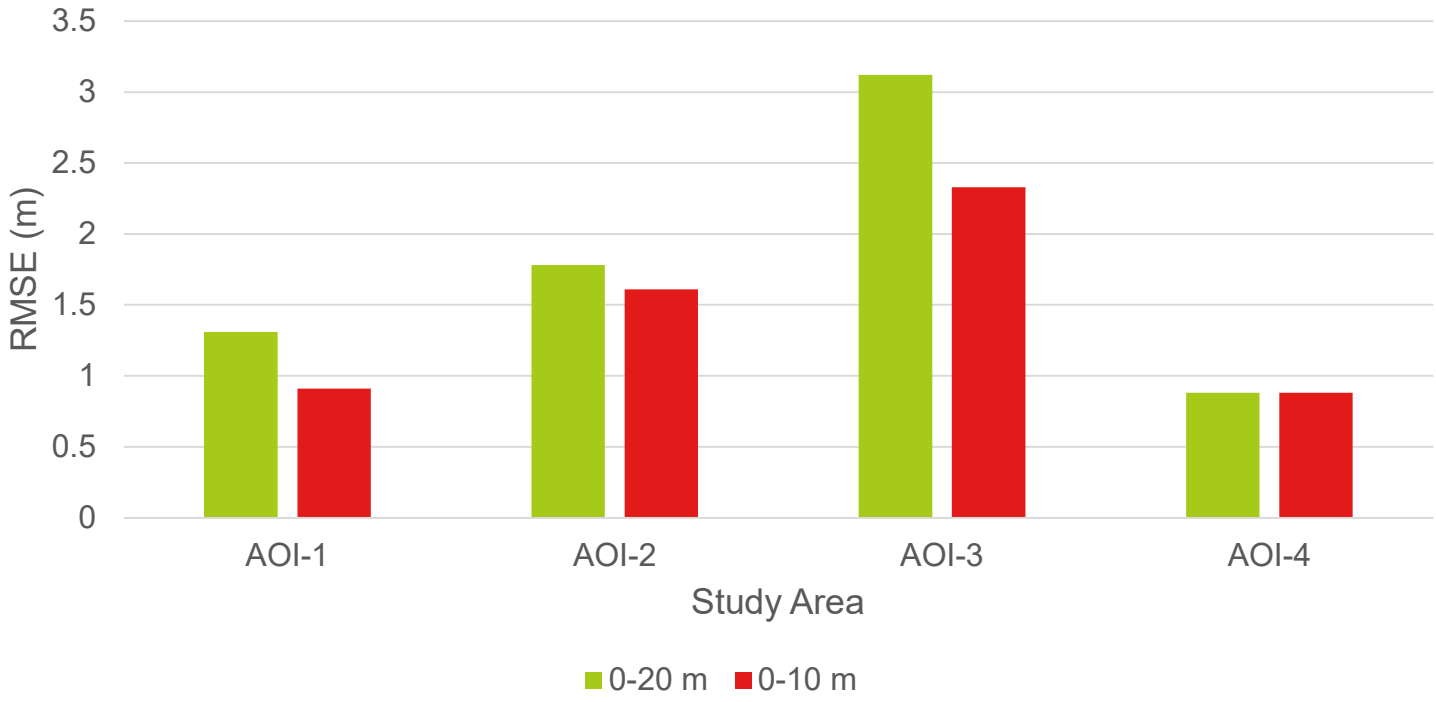
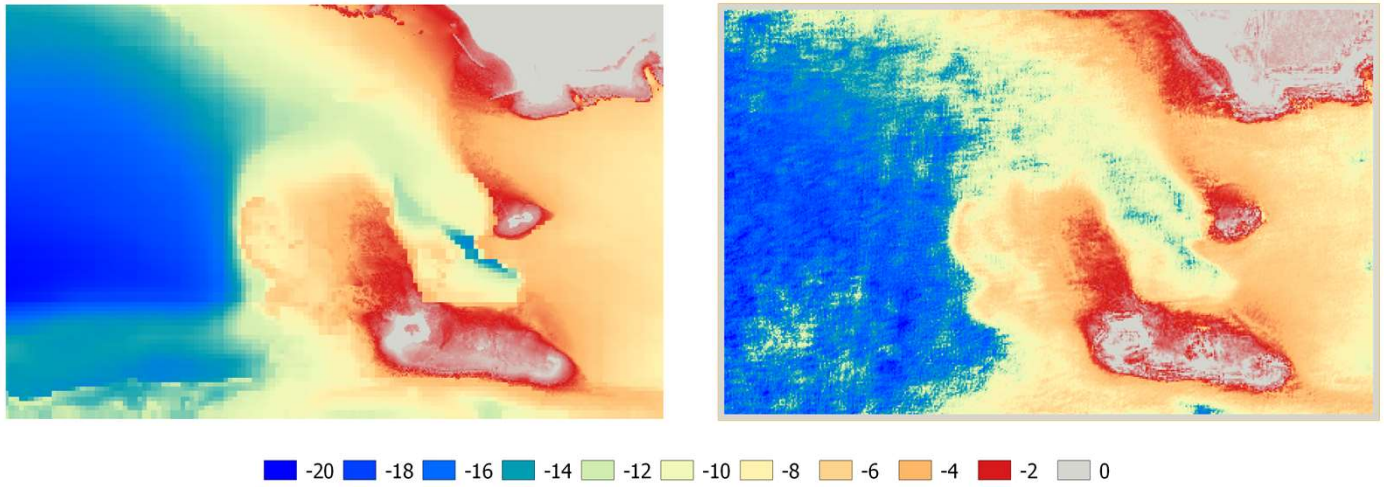
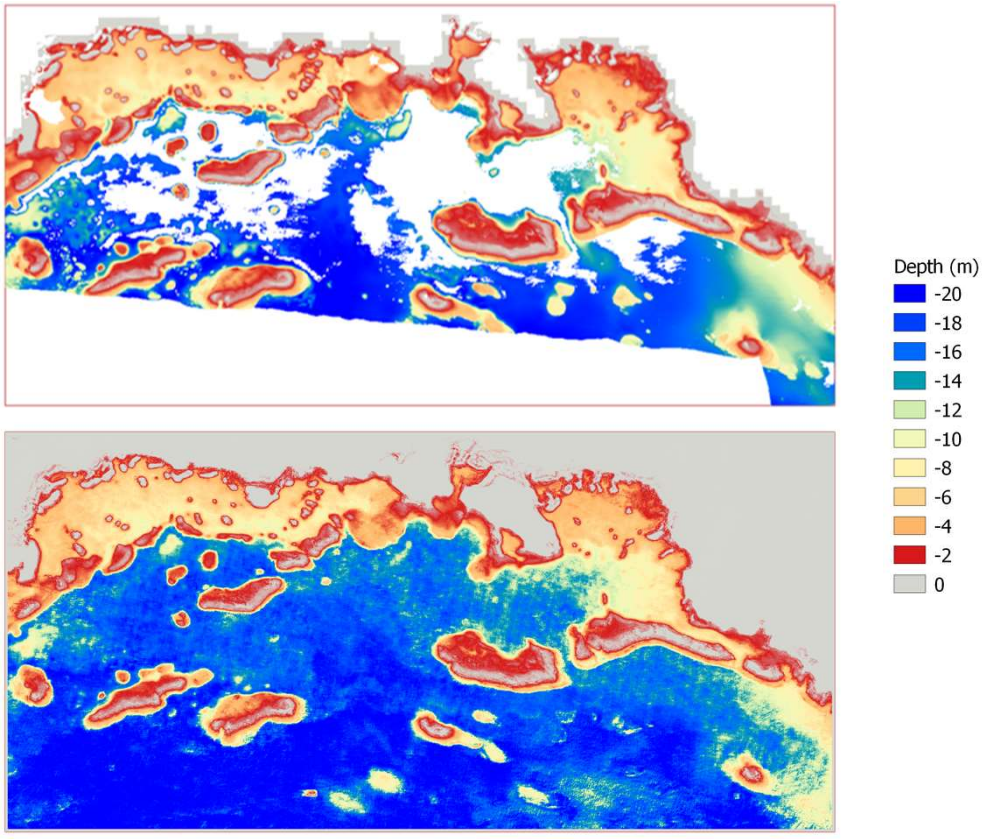
Accuracy


3.5
3
2.5
2
1.5
1
0.5
0
RMSE (m)
AOI-1
AOI-2
AOI-3
AOI-4
Study Area
0-20 m
0-10 m

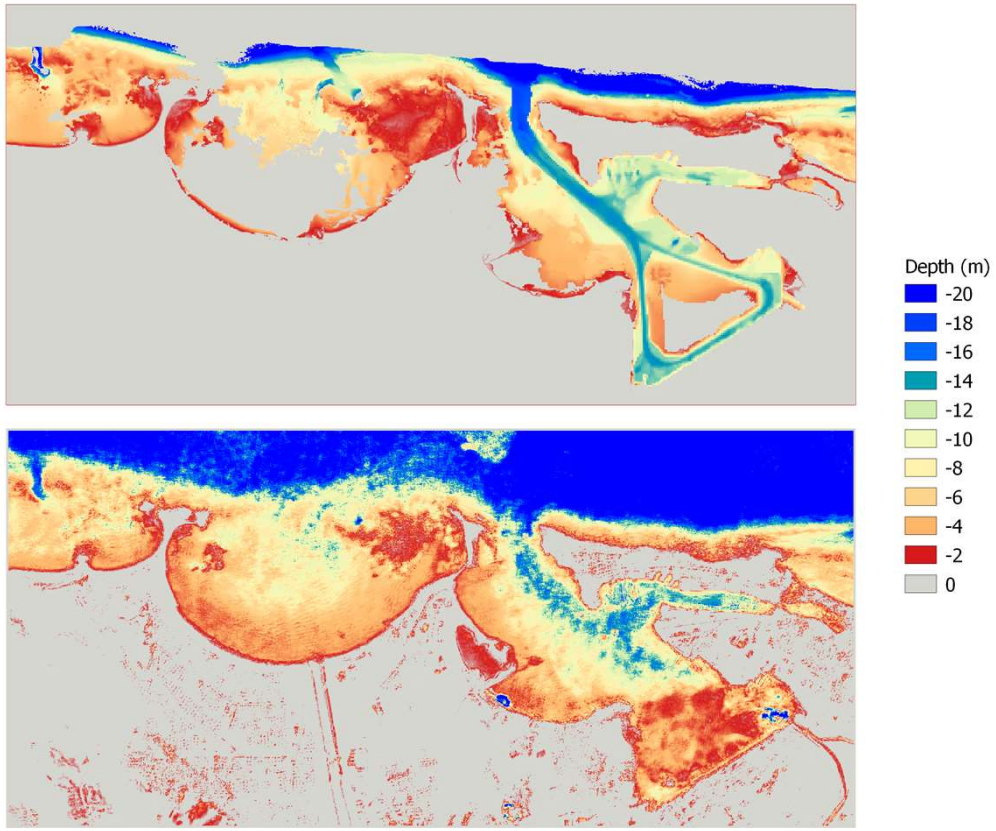
Ground truth vs SDB (AOI-1)



Ground truth vs SDB (AOI-2)



Ground truth vs SDB (AOI-3)



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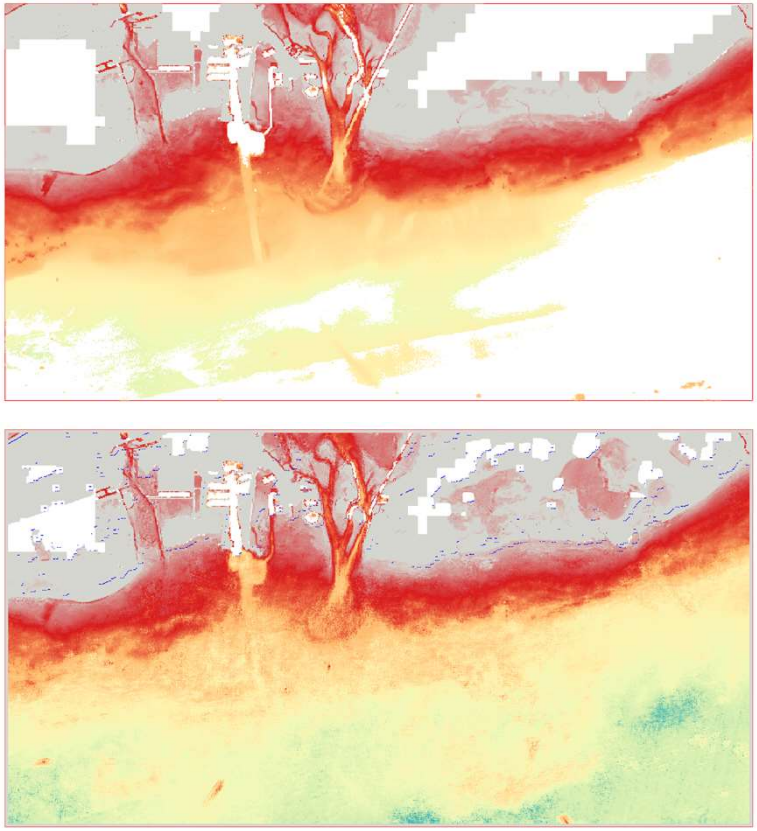
Ground truth vs SDB (AOI-4)



Accuracy (m)	CNN	Ratio Transform
MedAE	0.29	0.39

Experiment #3: SDB using uncorrected images

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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

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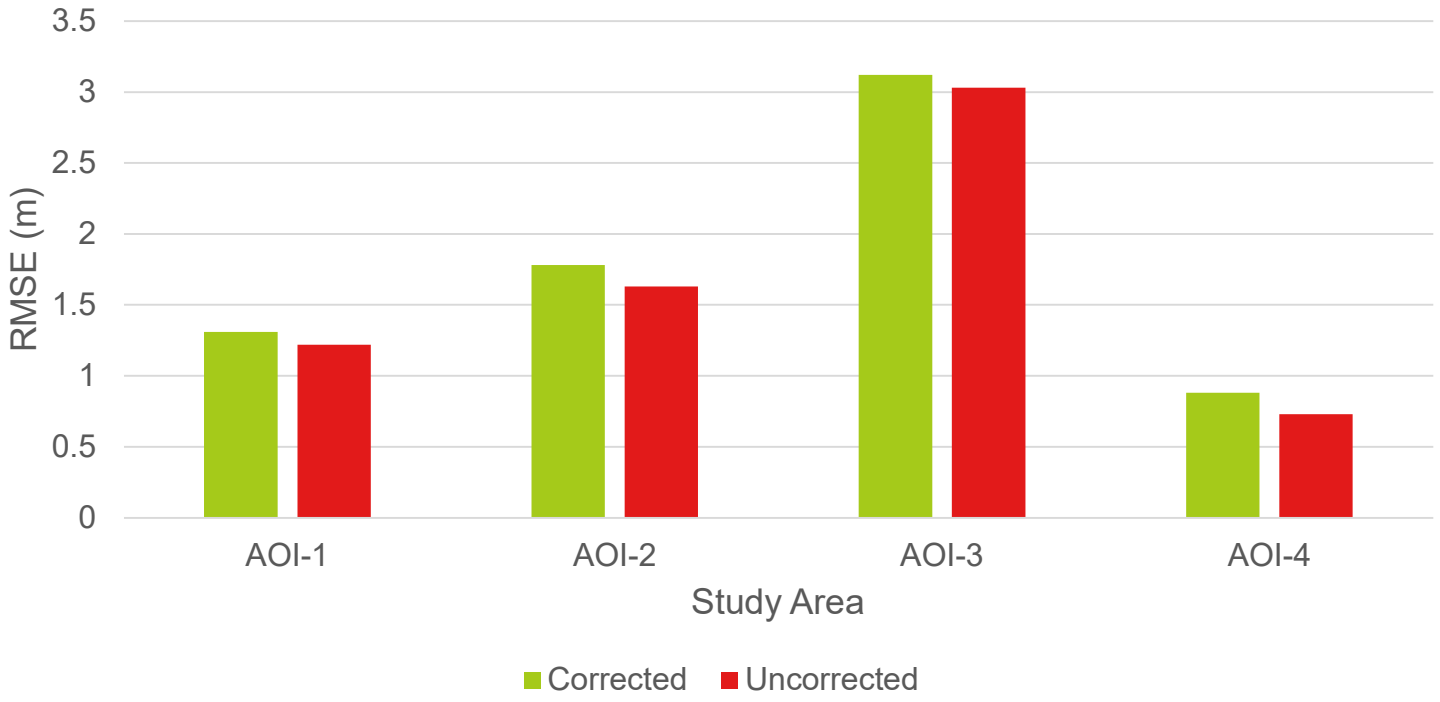
Accuracy



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Experiment #4: Multi-temporal images

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Setup

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

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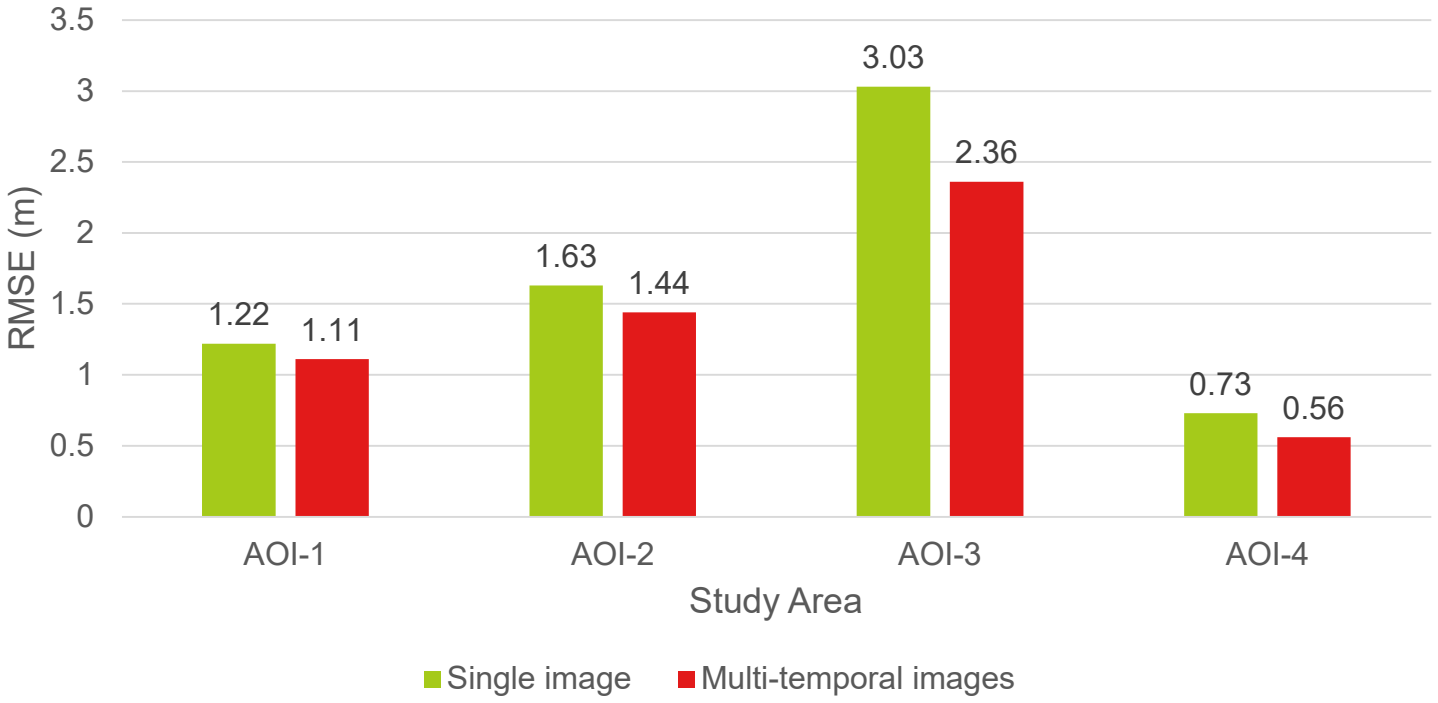
Accuracy



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Experiment #5: Transfer model

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Setup

Study area	AOI-5, AOI-6
Architecture	CNN3
Window size	9x9
Band combination	RGBNSS

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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

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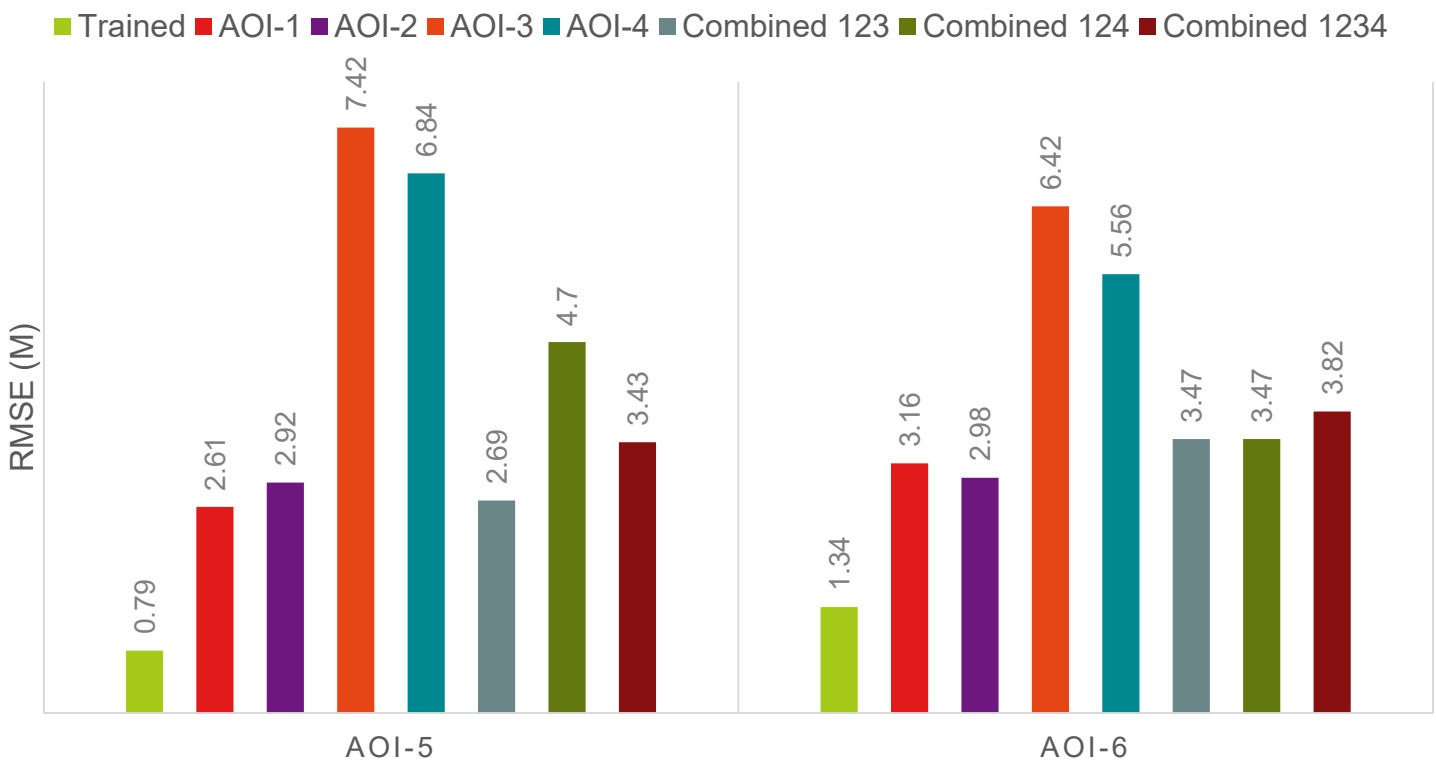
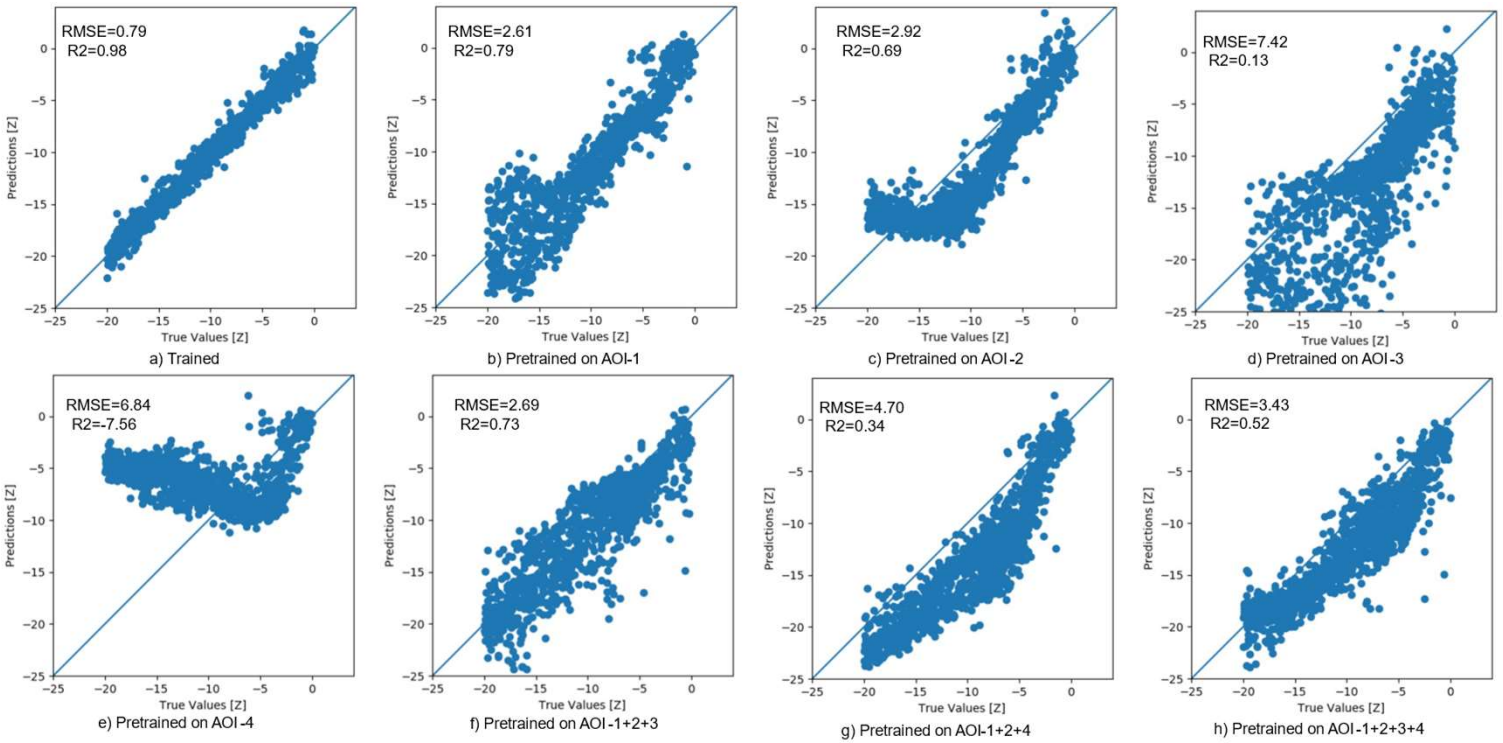
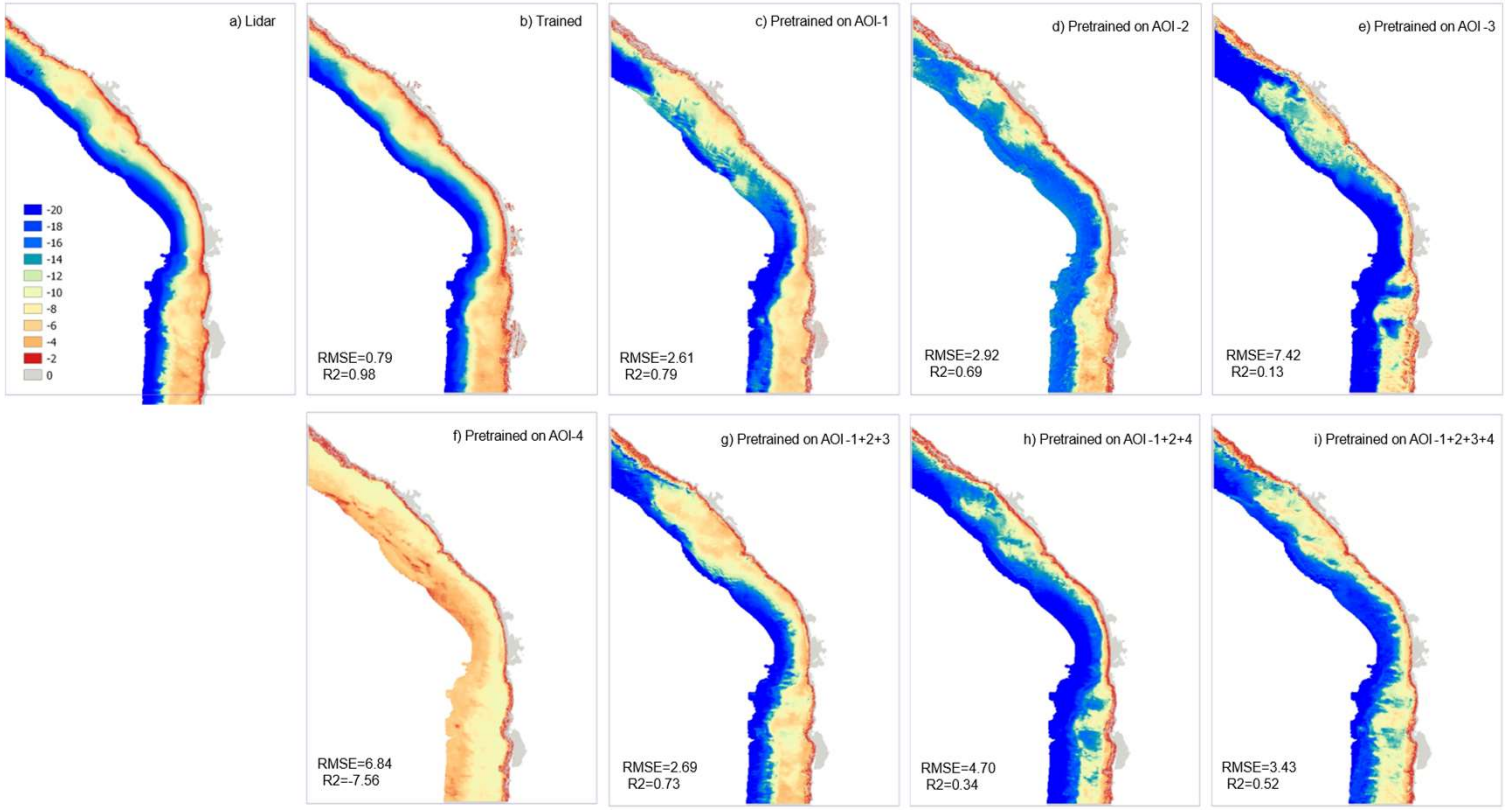
Accuracy


Trained
AOI-1
AOI-2
AOI-3
AOI-4
Combined 123
Combined 124
Combined 1234
RMSE (M)
0.79
2.61
2.92
7.42
6.84
2.69
4.7
3.43
1.34
3.16
2.98
6.42
5.56
3.47
3.47
3.82
AOI-5
AOI-6

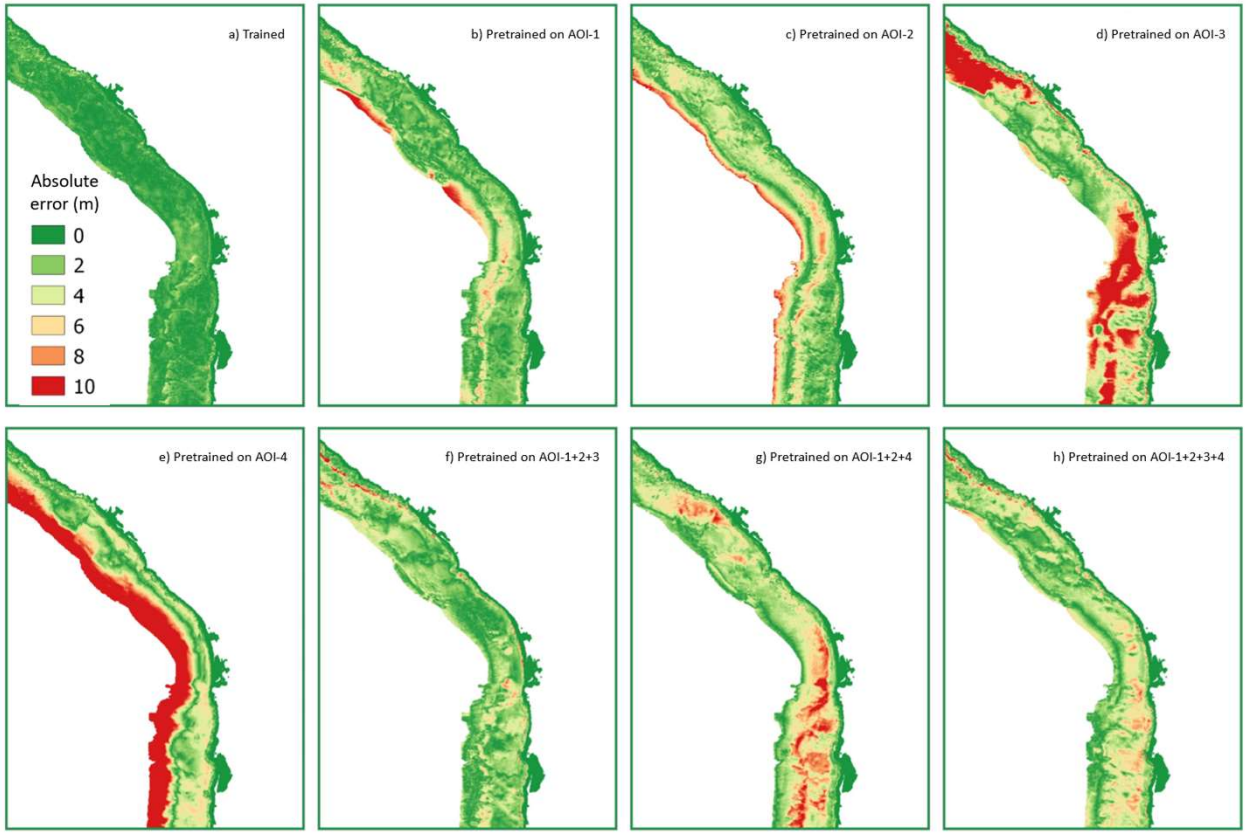
Prediction vs ground truth AOI-5



SDB AOI-5


a) Lidar
-20
-18
-16
-14
-12
-10
-8
-6
-4
-2
0
b) Trained
RMSE=0.79
R2=0.98
c) Pretrained on AOI-1
RMSE=2.61
R2=0.79
d) Pretrained on AOI-2
RMSE=2.92
R2=0.69
e) Pretrained on AOI-3
RMSE=7.42
R2=0.13
f) Pretrained on AOI-4
RMSE=6.84
R2=-7.56
g) Pretrained on AOI-1+2+3
RMSE=2.69
R2=0.73
h) Pretrained on AOI-1+2+4
RMSE=4.70
R2=0.34
i) Pretrained on AOI-1+2+3+4
RMSE=3.43
R2=0.52

Error map AOI-5



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Experiment #6: SDB production in a larger area

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Setup

Study area	Oahu island
Architecture	CNN3
Window size	9x9
Band combination	RGBNSS
Training data	AOI-5 + AOI-6

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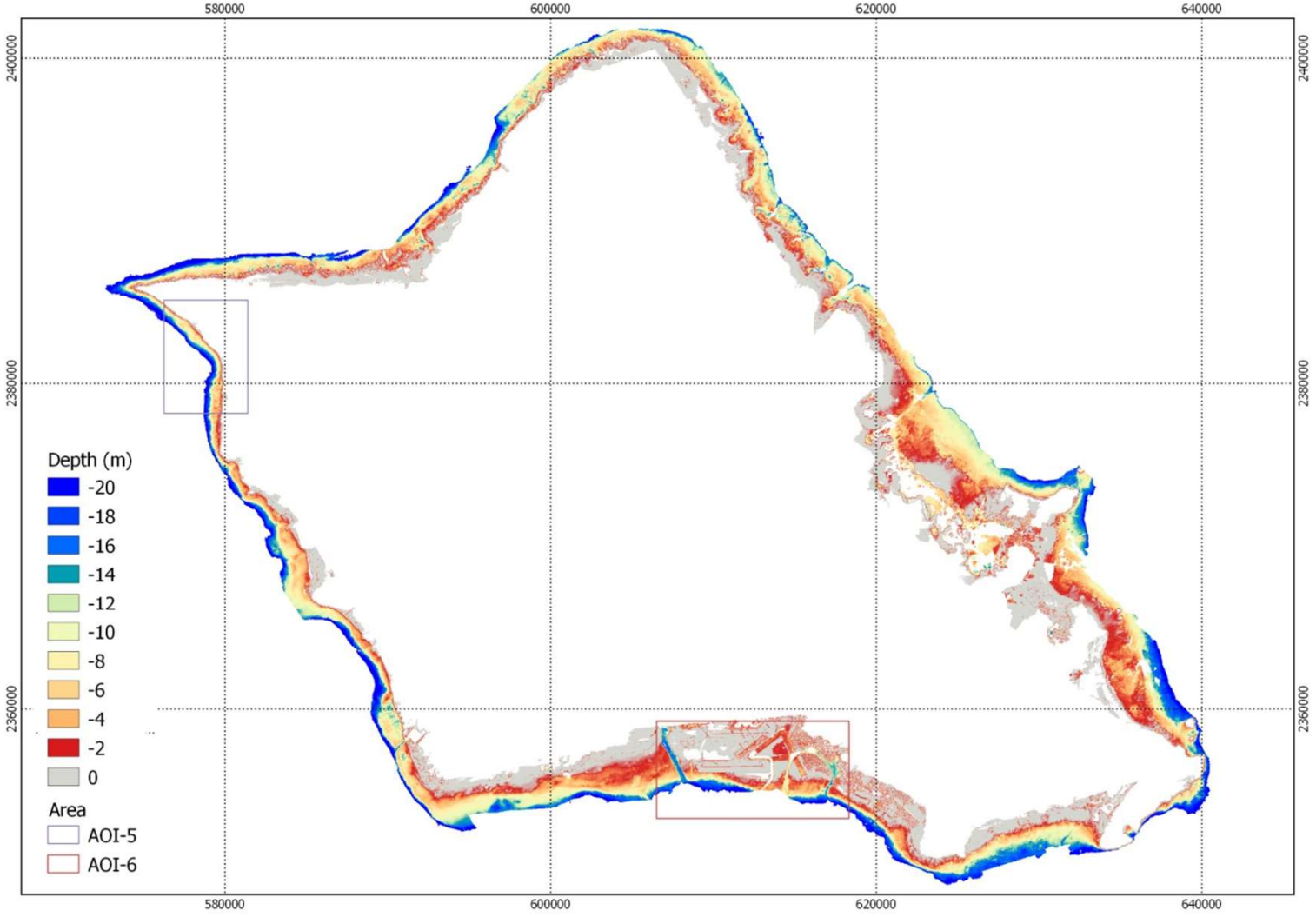
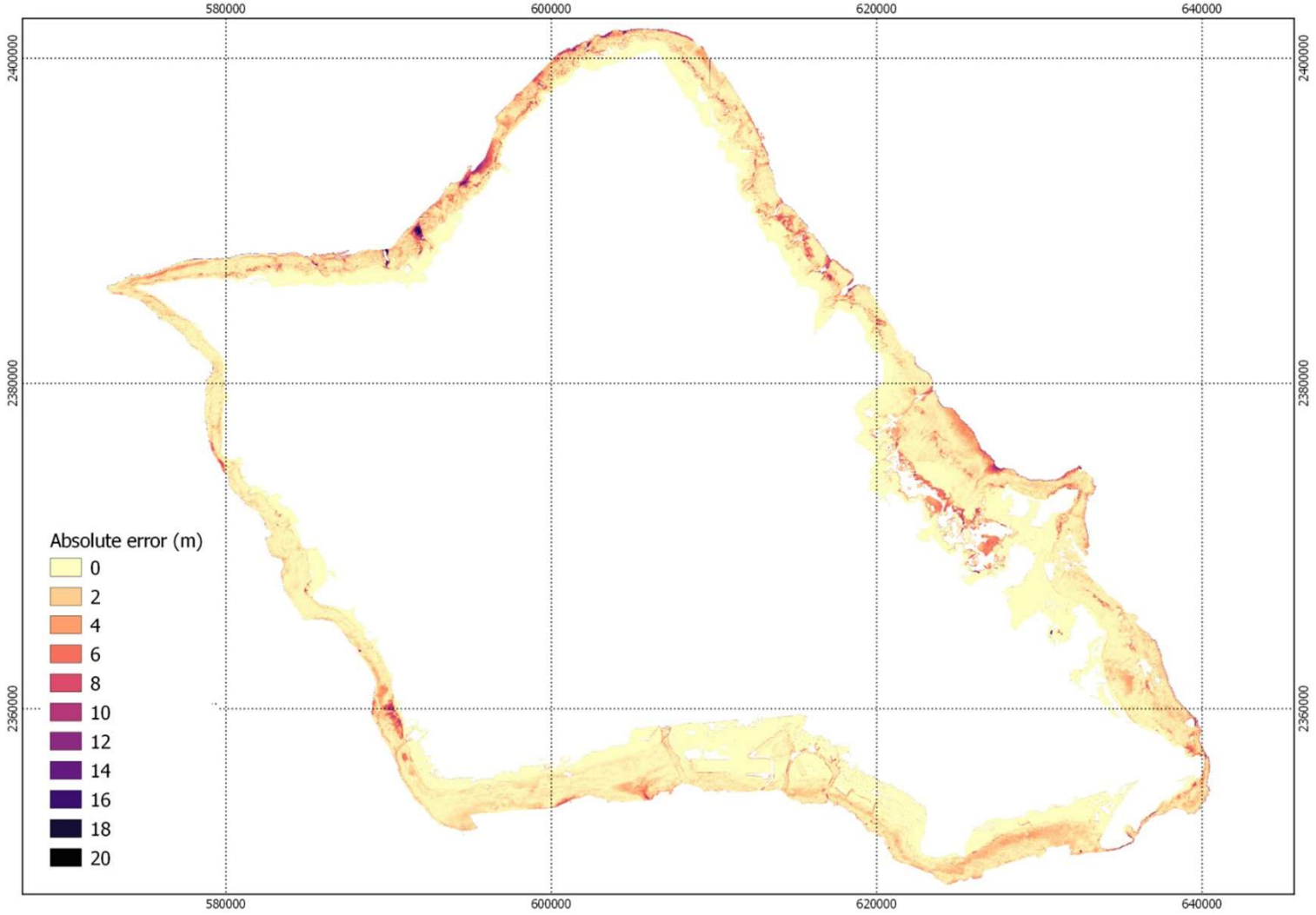

580000
600000
620000
640000
2400000
2380000
2360000
Depth (m)
-20
-18
-16
-14
-12
-10
-8
-6
-4
-2
0
Area
AOI-5
AOI-6


580000
600000
620000
640000
2400000
2380000
2360000
Absolute error (m)
0
2
4
6
8
10
12
14
16
18
20

Conclusions

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What kind of preprocessing is needed for the data sets?

- No additional preprocessing is required

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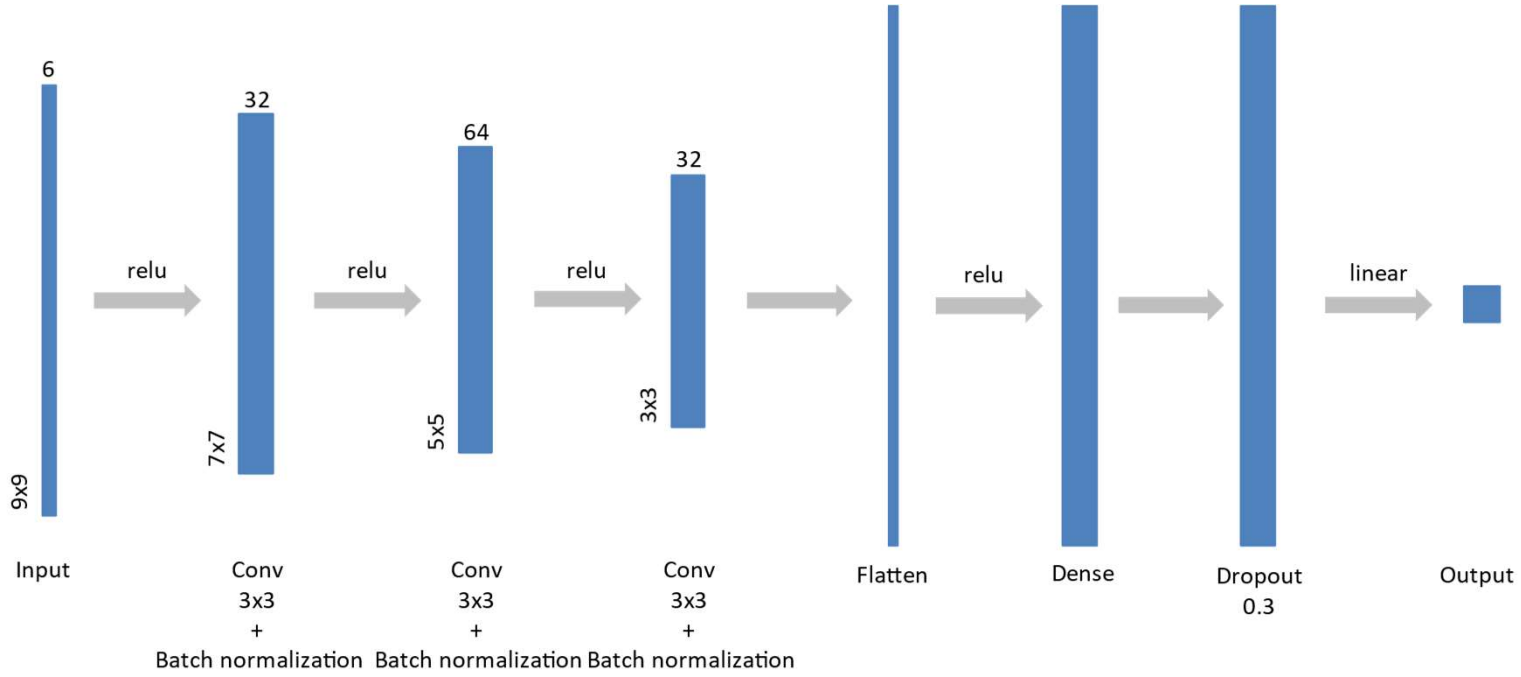
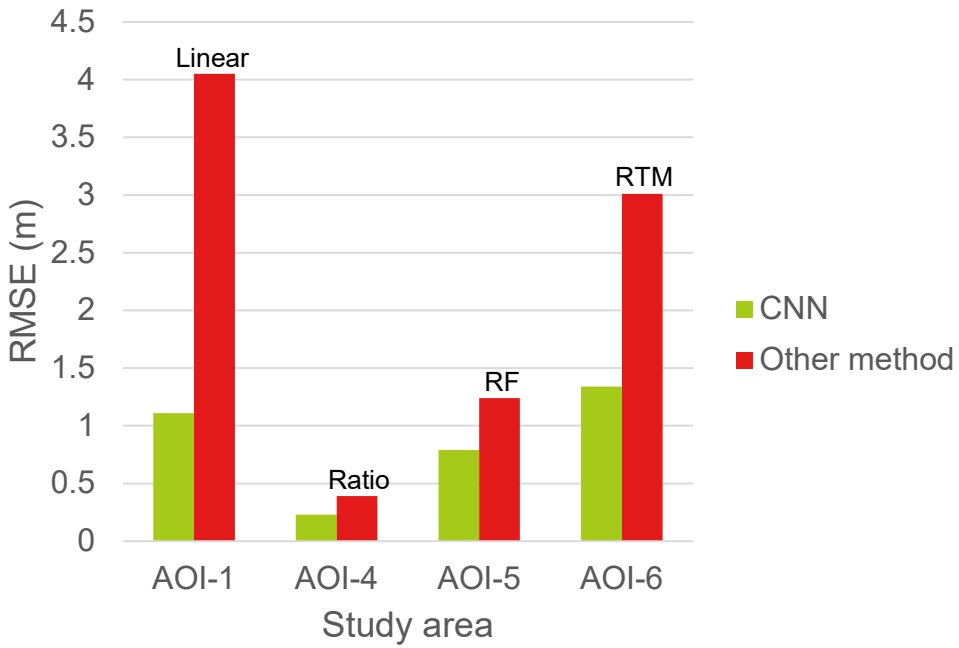
What kind of CNN architecture can be used for SDB?



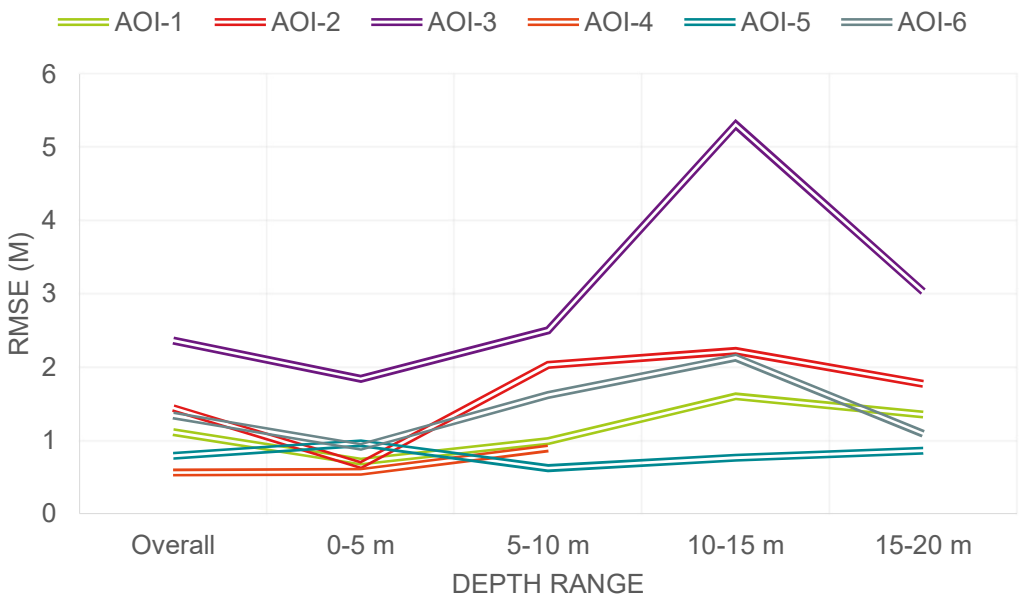
What is the accuracy of the method?

- Compared to other methods



What is the accuracy of the method?

- In different depth ranges and locations



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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

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Future work

- Balancing the training data
- Verification using another data source
- SDB in the colder water and freshwater

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Thank you!

Repository link:
http://repository.tudelft.nl
https://github.com/yustisiardhitasari/sdbcnn.git