Machine Learning for Dune Erosion

Applying Convolutional Neural Networks to Predict Post-Storm Profile Shapes

Koen van Asselt

12-06-2024

Who am I

- Koen van Asselt
- Deltares since September 2022
  - Internship
  - Junior Employee

- Graduated Hydraulic Engineering at TU Delft in June 2023
- Applied Morphodynamics team
  - Coastal Hazards
  - Compound flooding

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XBeach

U-Net

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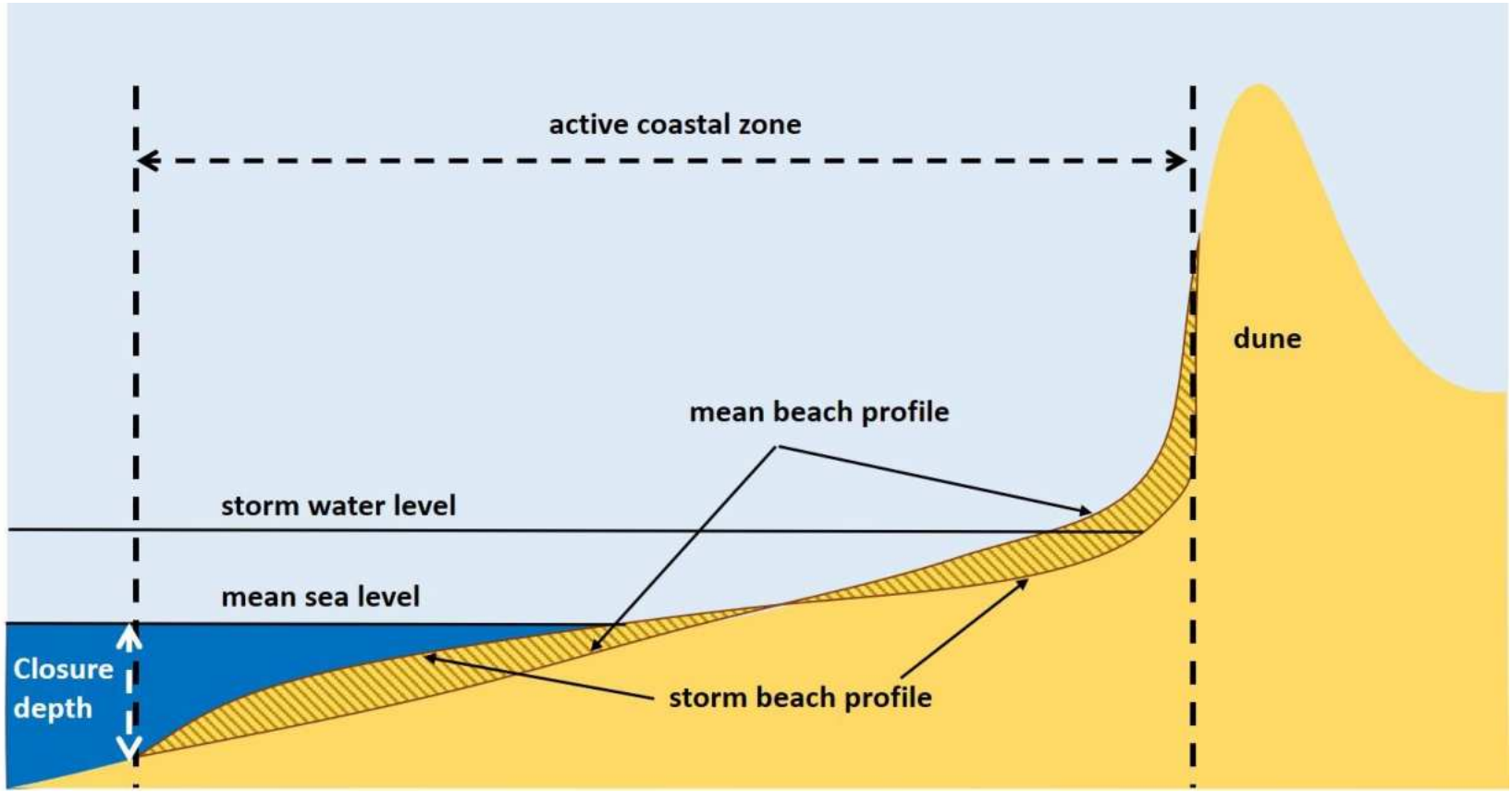
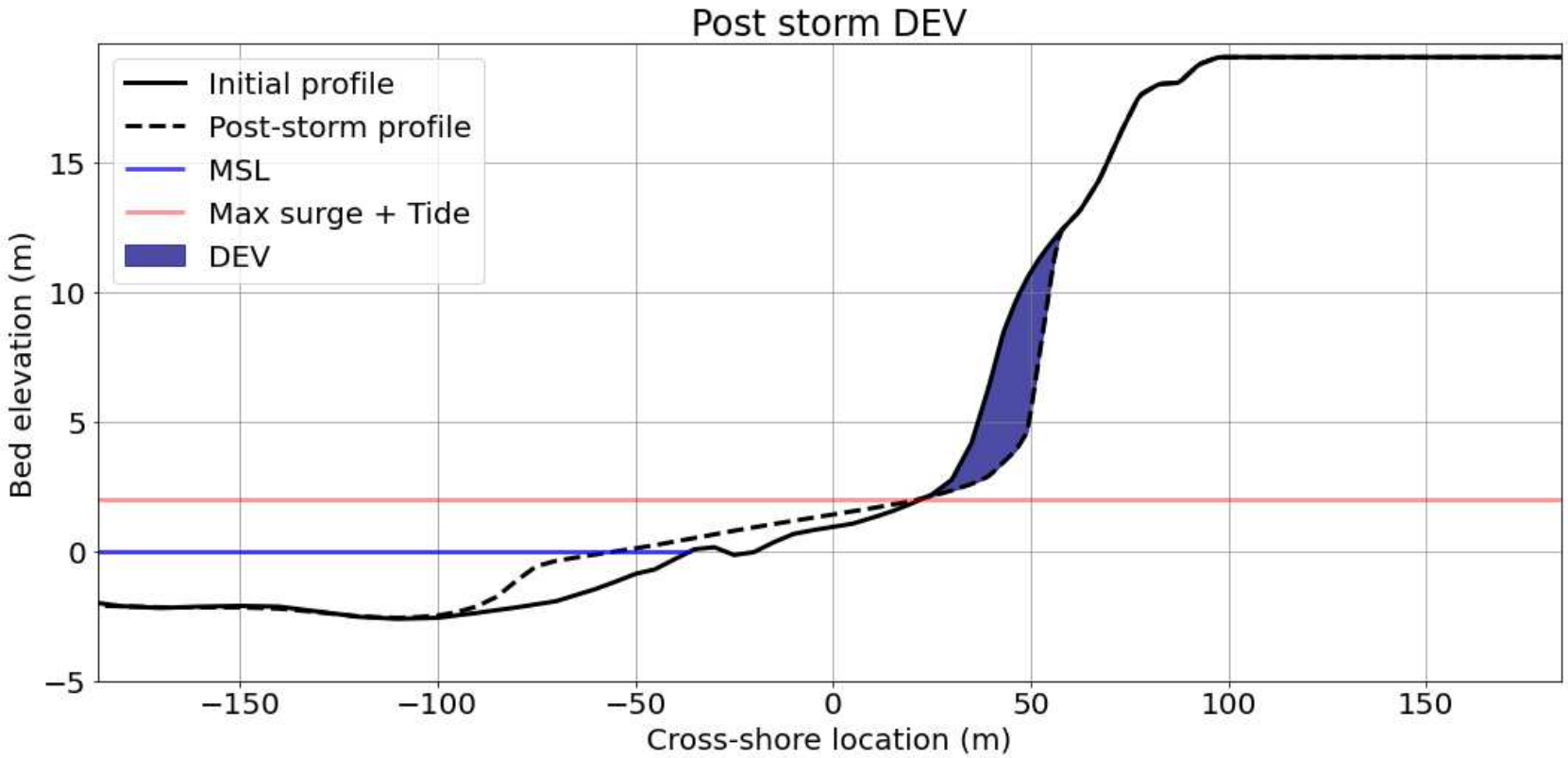
INTRODUCTION



INTRODUCTION

XBeach simulations



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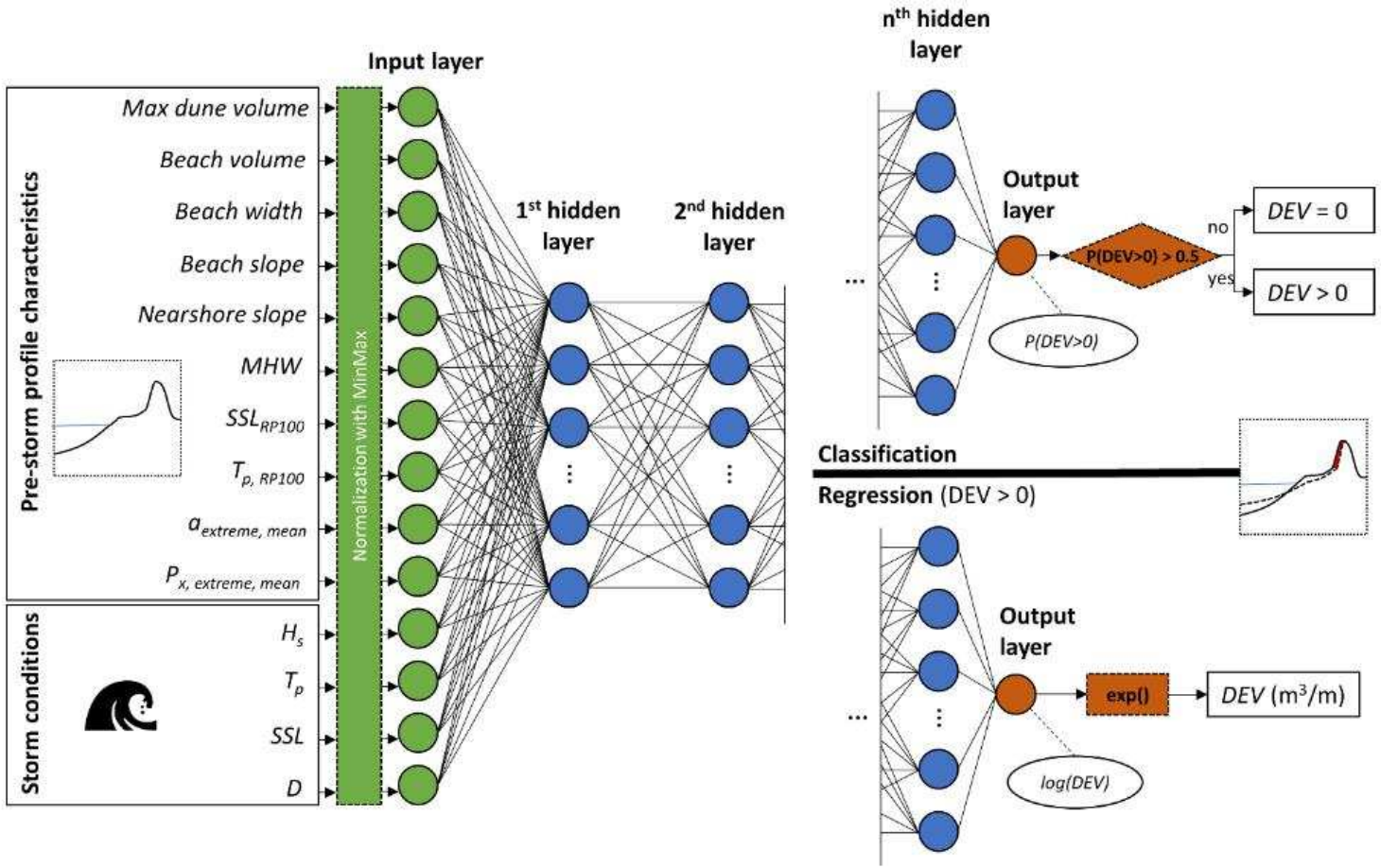
INTRODUCTION

Estimating dune erosion at the regional scale using a meta-model based on Neural Networks – Athanasiou et. al. (2022)



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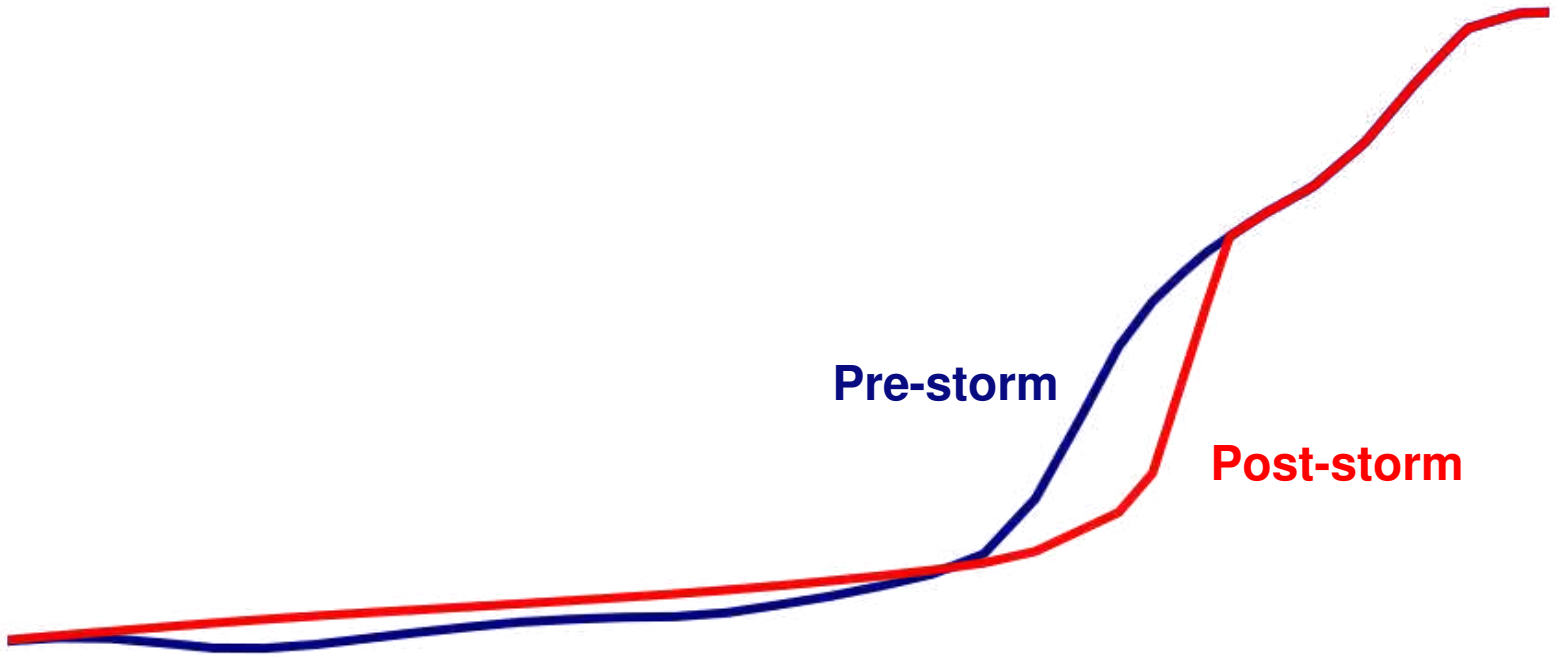

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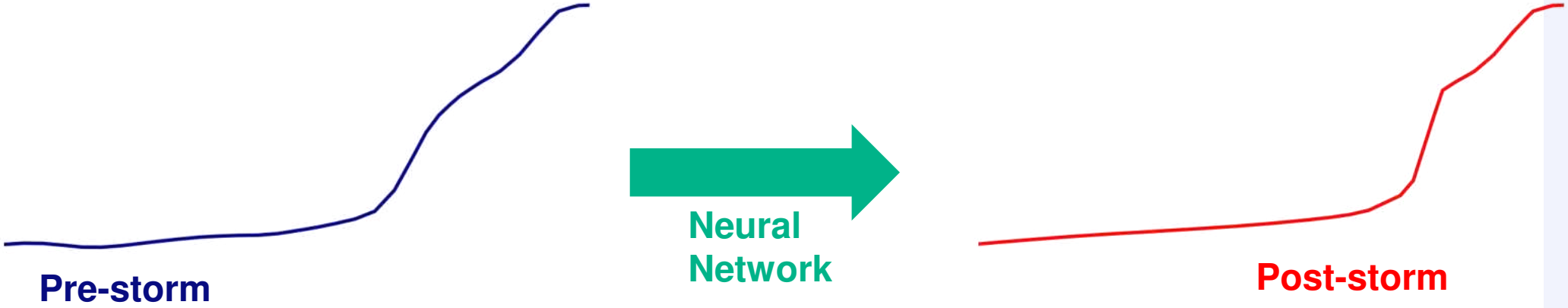

Enabling fast prediction of **post-storm sandy profiles** along the Holland Coast using surrogate modelling and XBeach.

enabling delta life

INTRODUCTION

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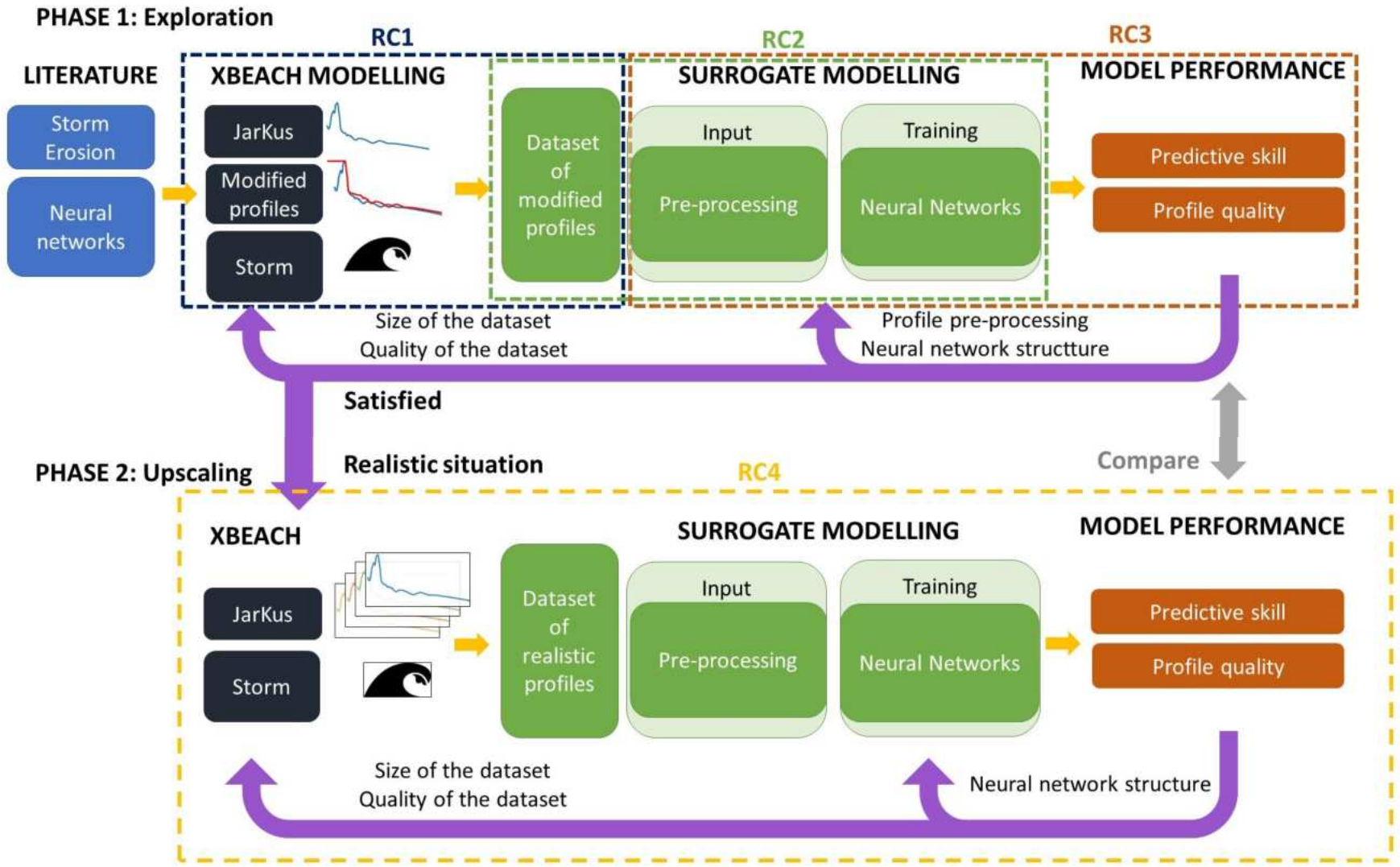

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METHODS: XBEACH

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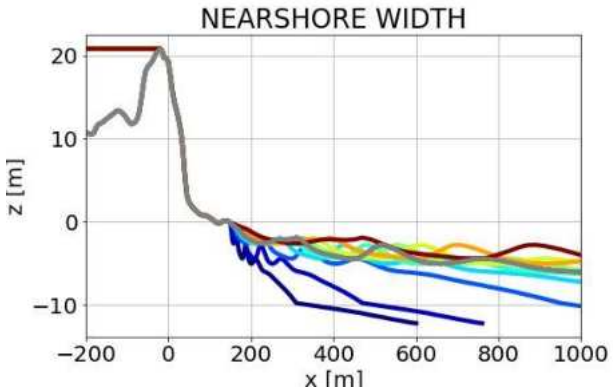

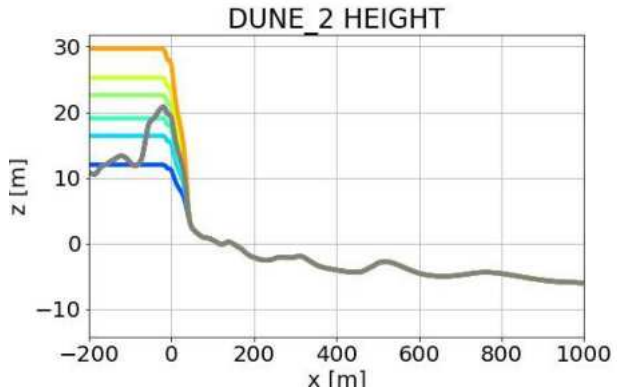

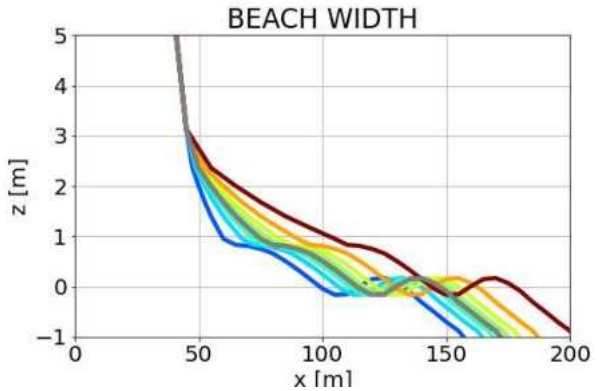

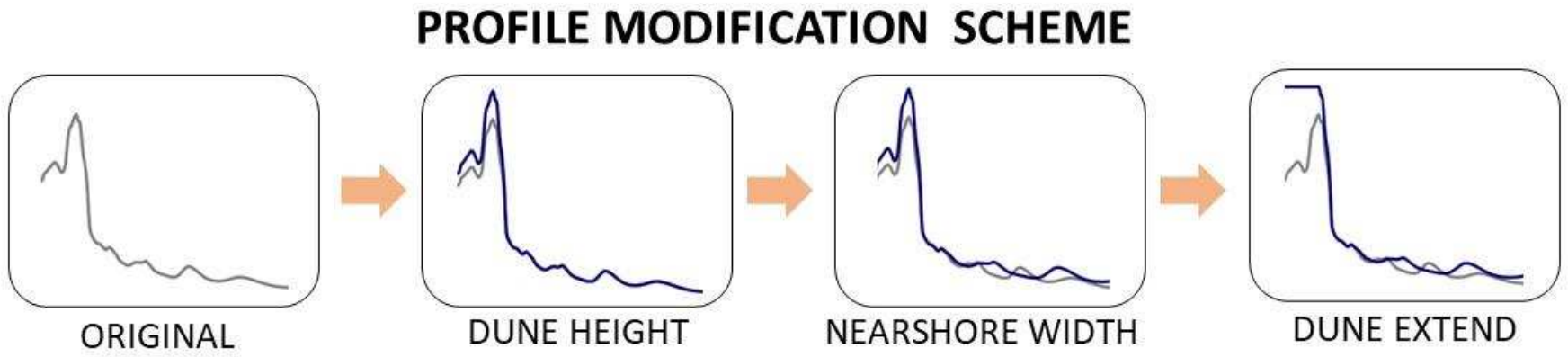

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METHODS: XBEACH

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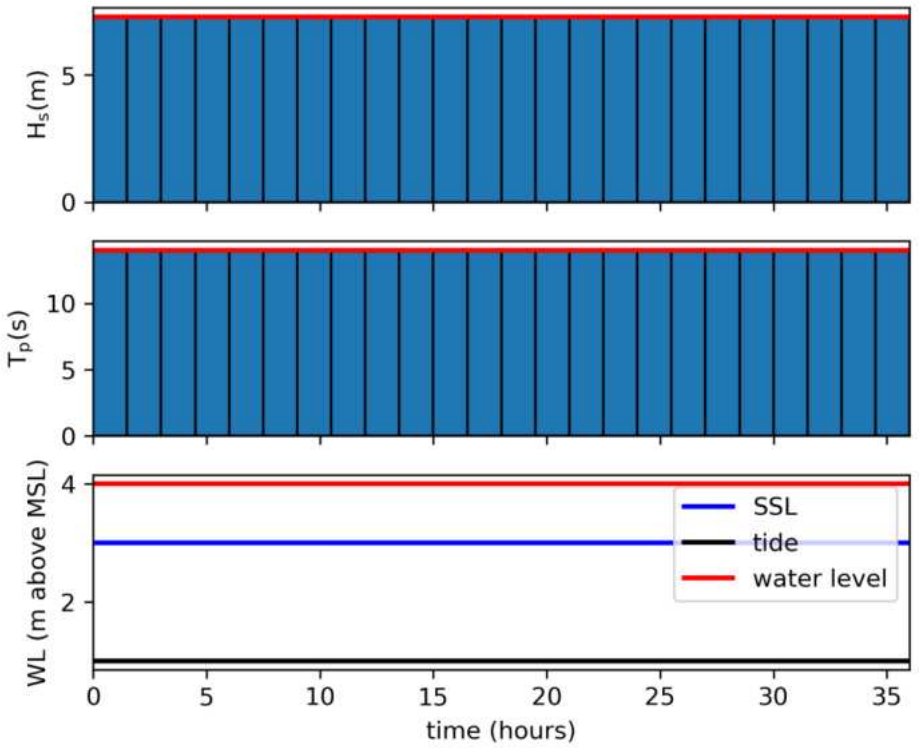
One storm with stationary conditions



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METHODS: XBEACH

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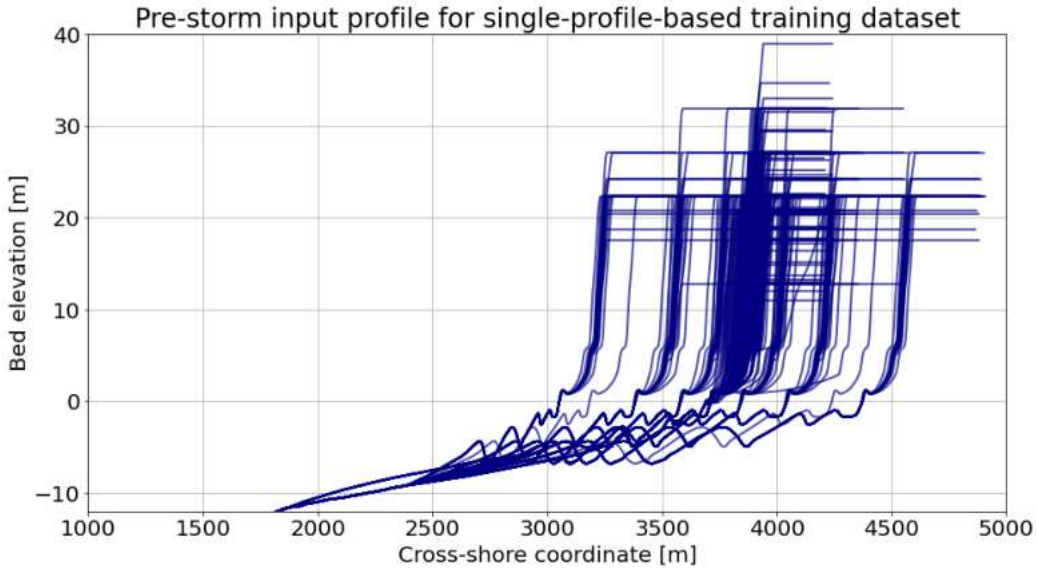
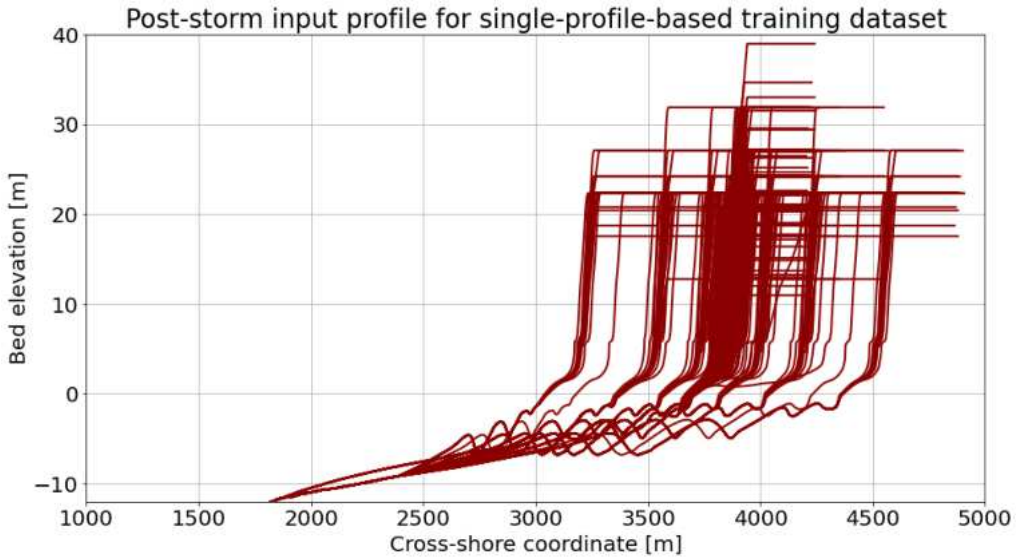
Pre-storm



Post-storm



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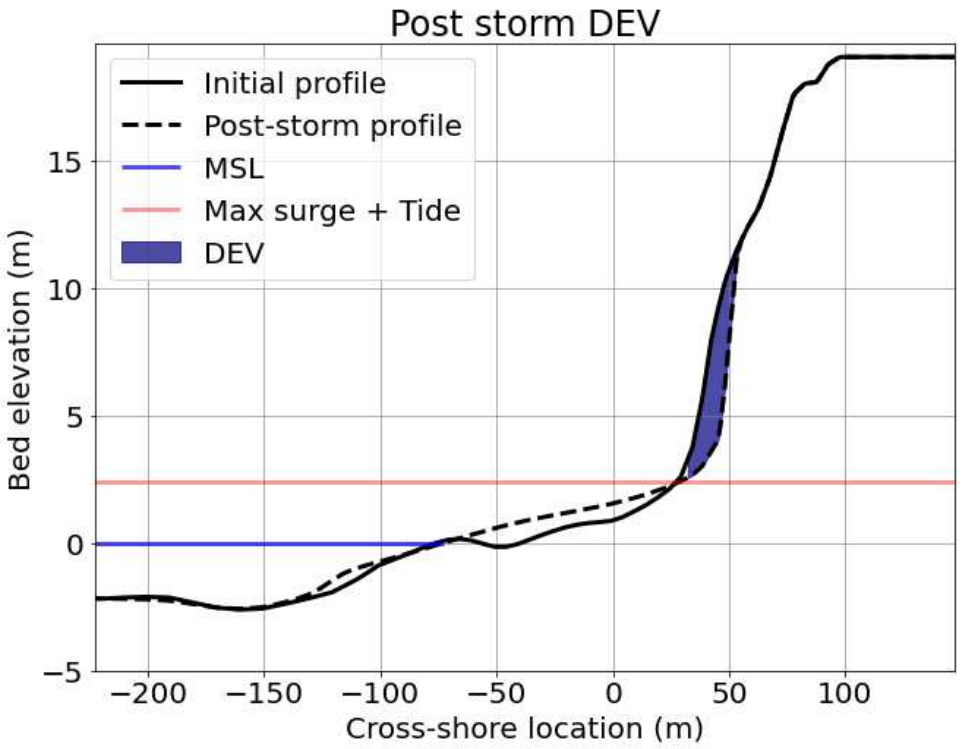

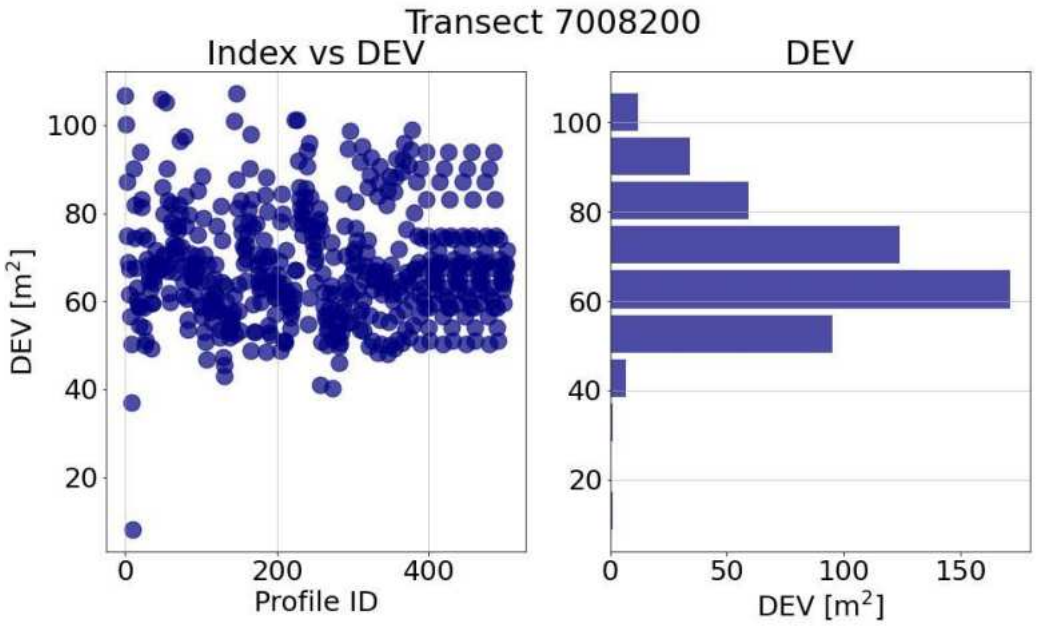

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METHODS: XBEACH

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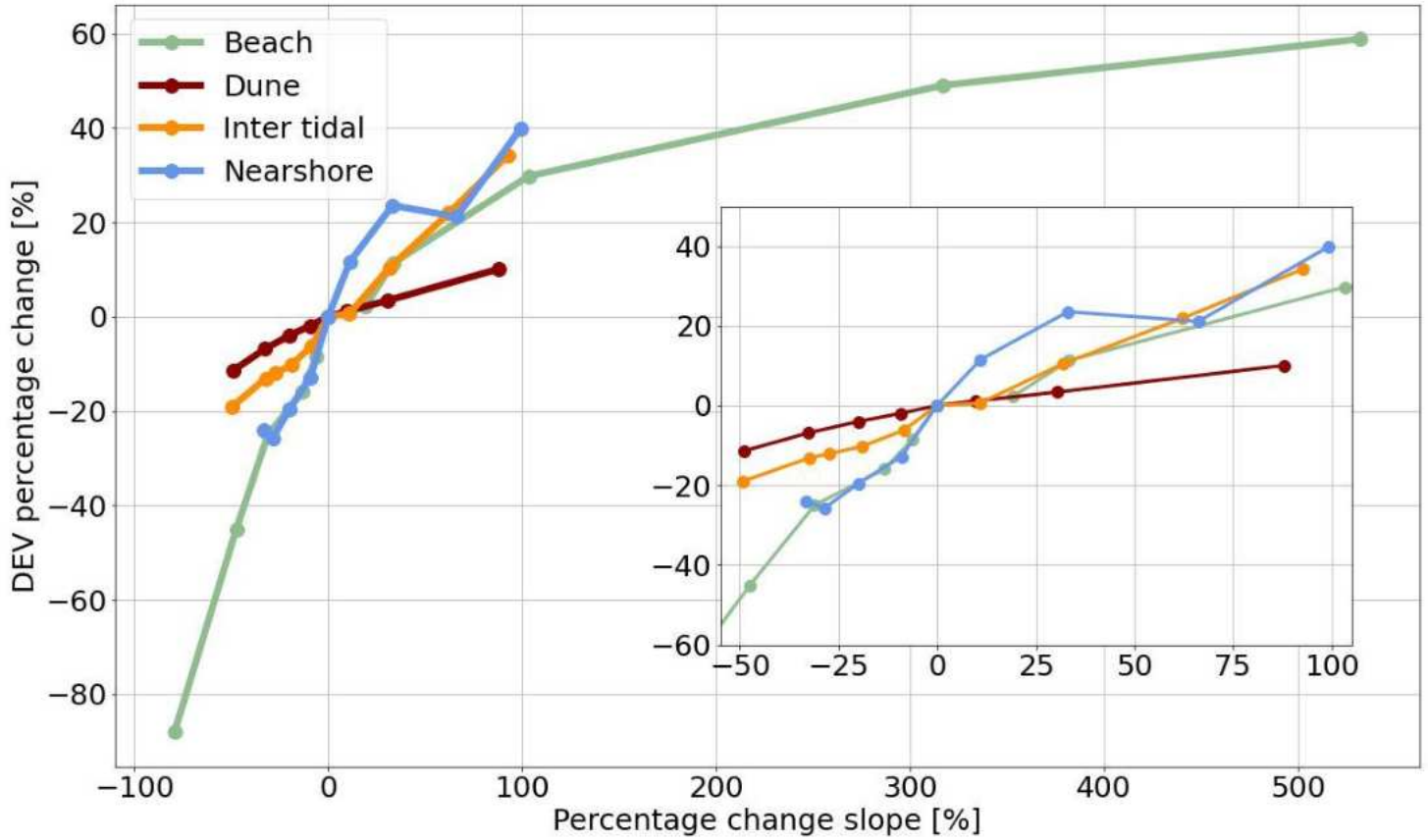

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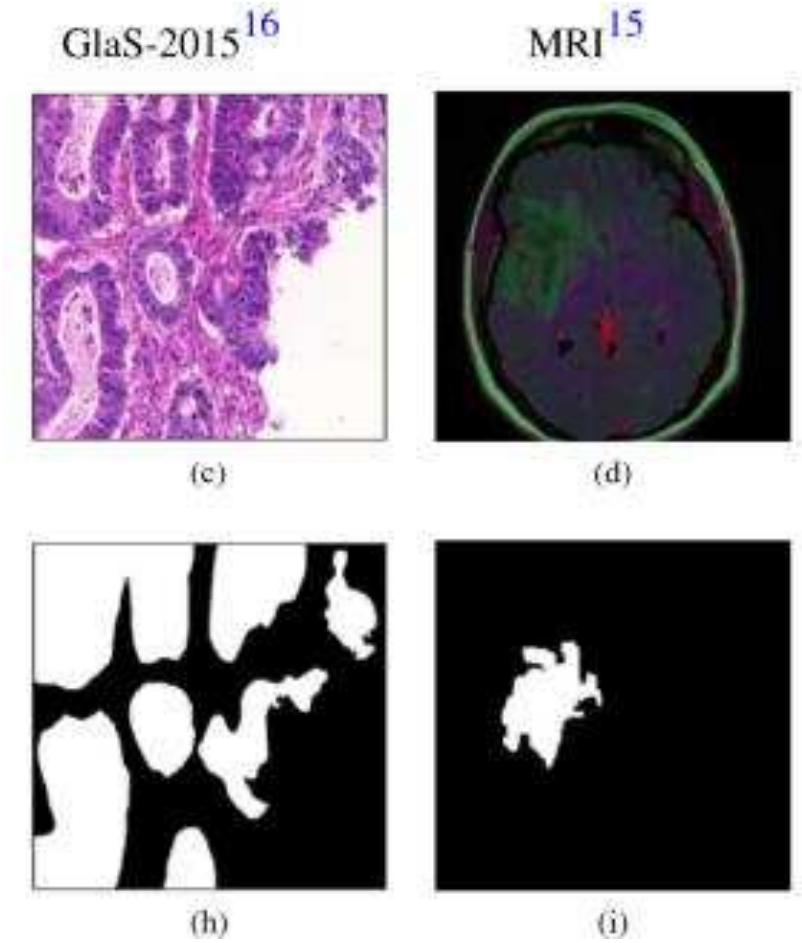
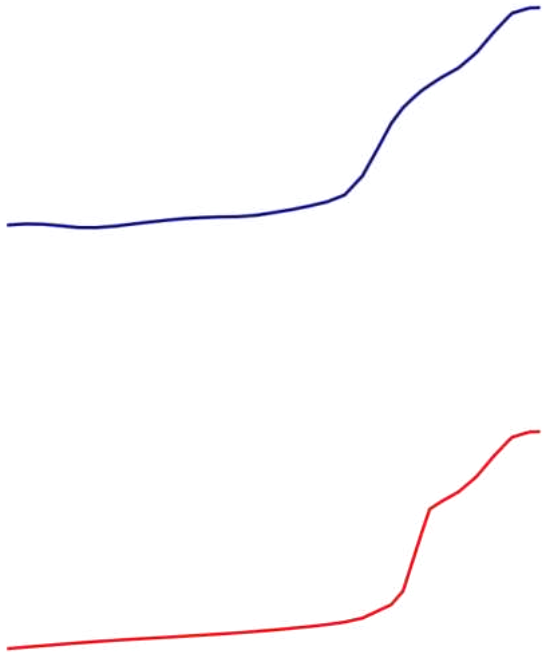
U-Net



Dune erosion



U-Net

- Introduction
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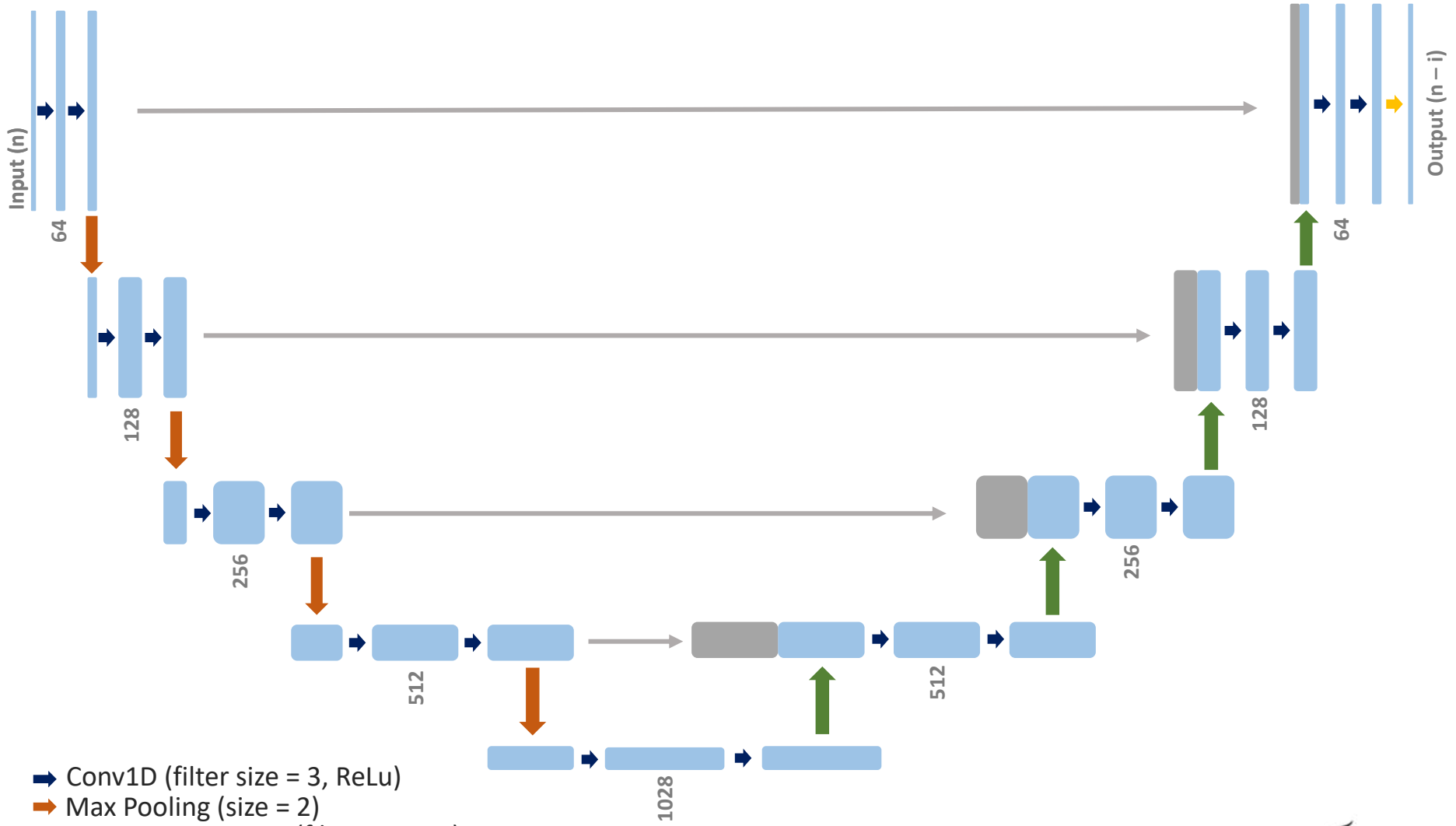

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METHODS: U-Net Structure

- Introduction
- XBeach
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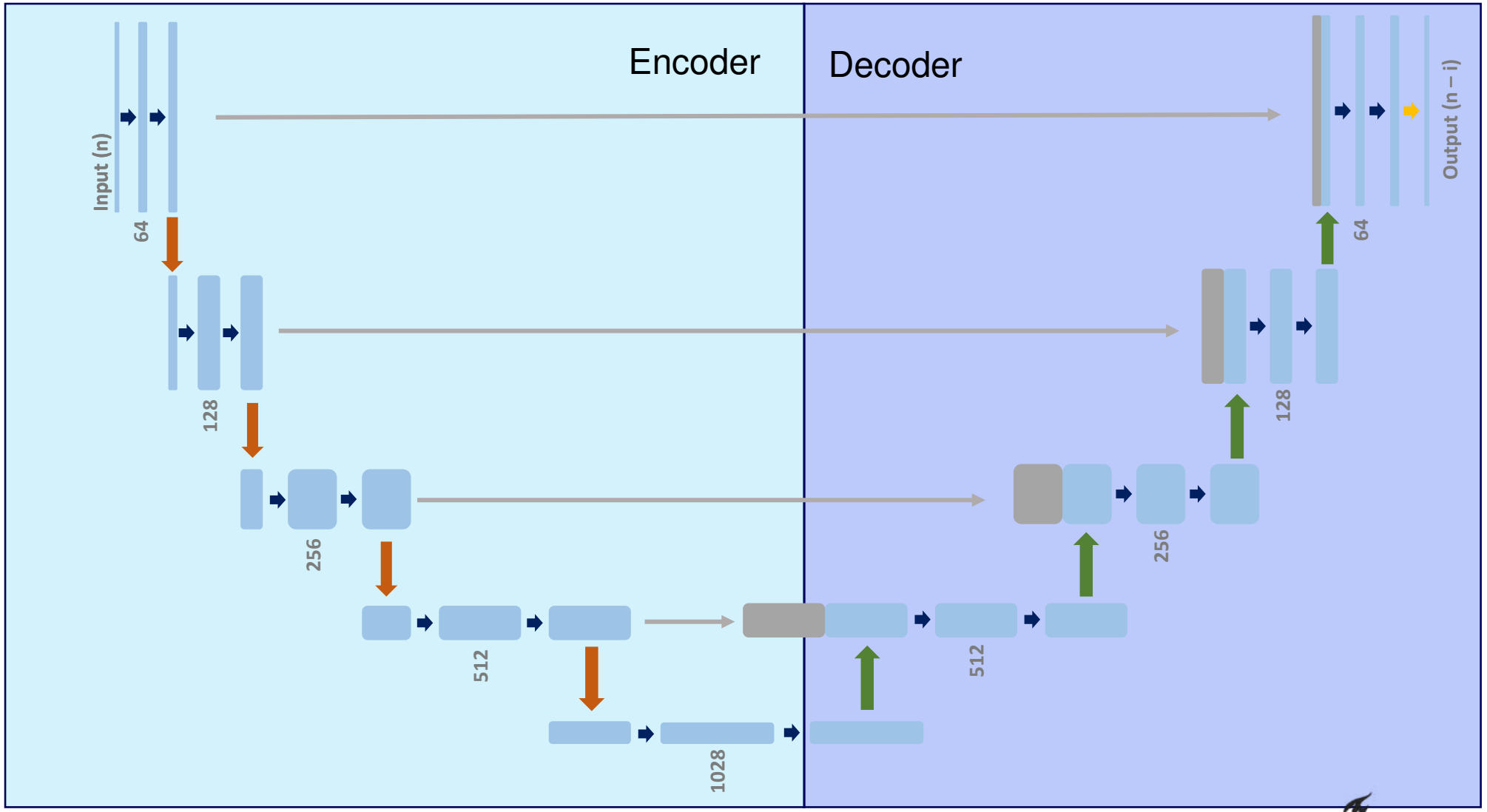

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U-Net: Network depth

- Introduction
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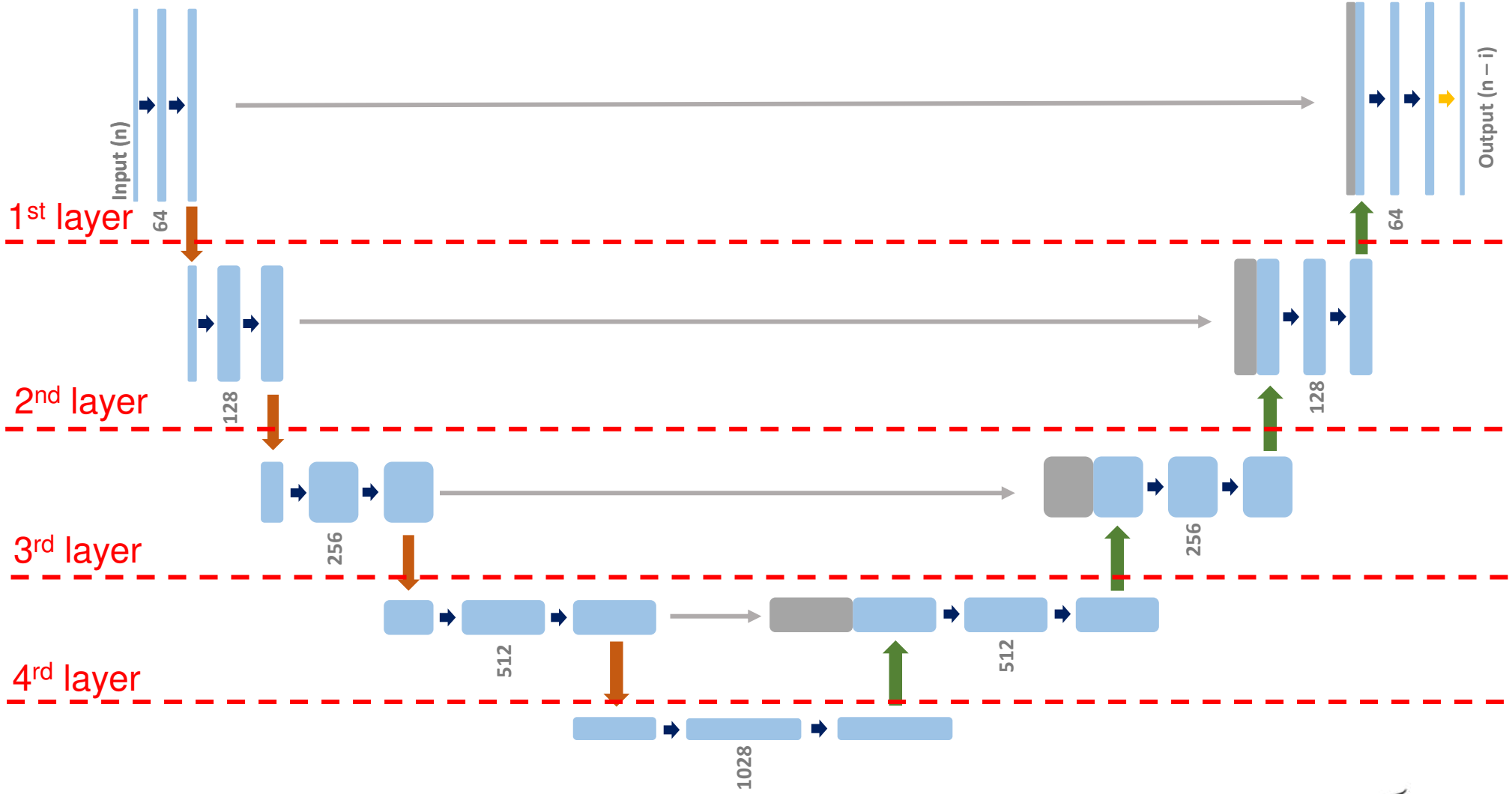

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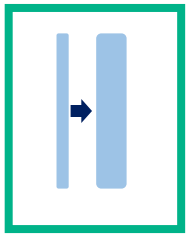
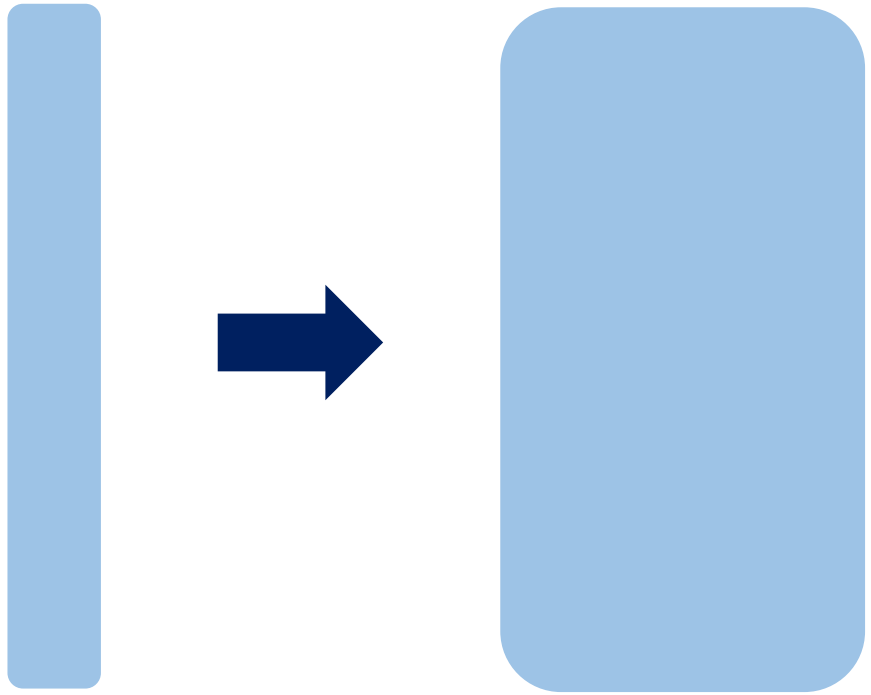
U-Net: Convolutional block



Skip connections

U-Net: Convolutional block



Convolution
Pooling layer

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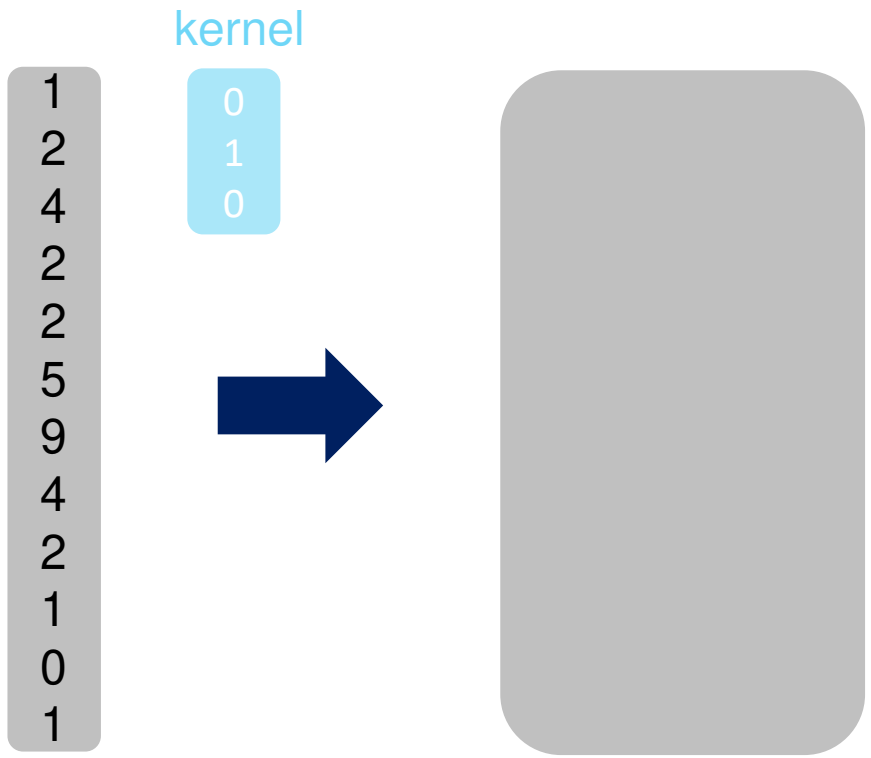
U-Net: Convolutional block



Convolution
Pooling layer

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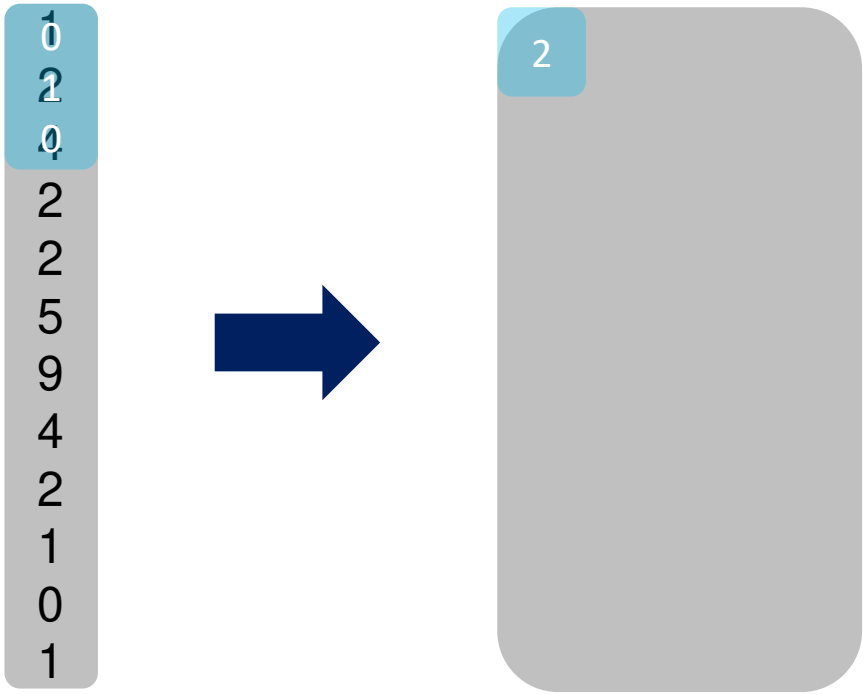
U-Net: Convolutional block



Convolution
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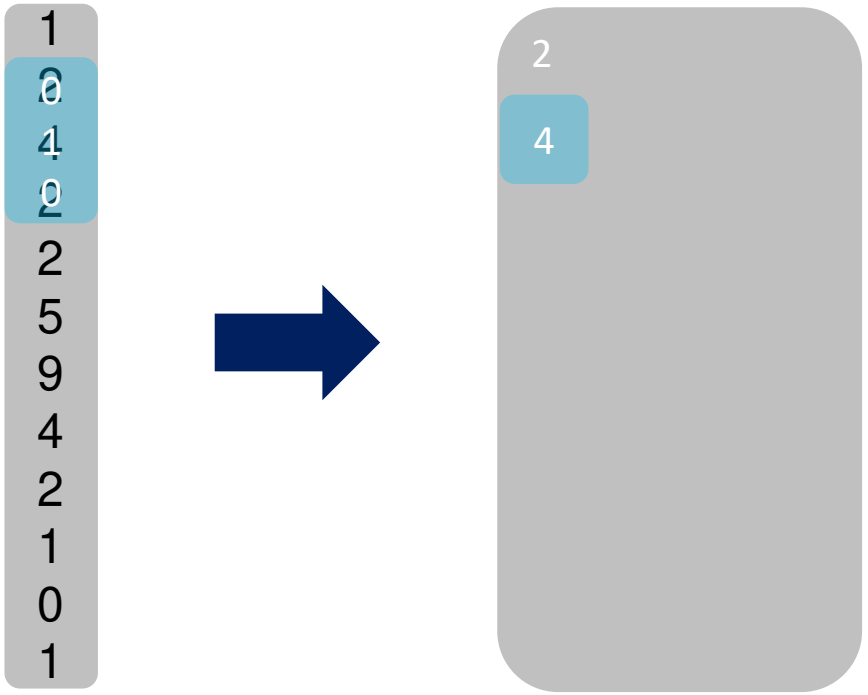
U-Net: Convolutional block



Convolution
Pooling layer

U-Net: Convolutional block

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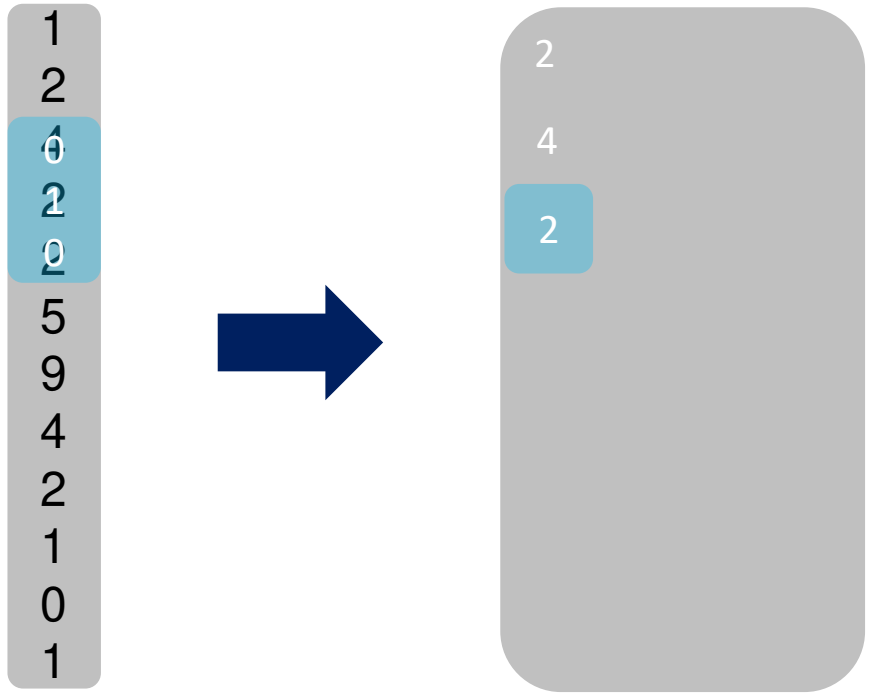
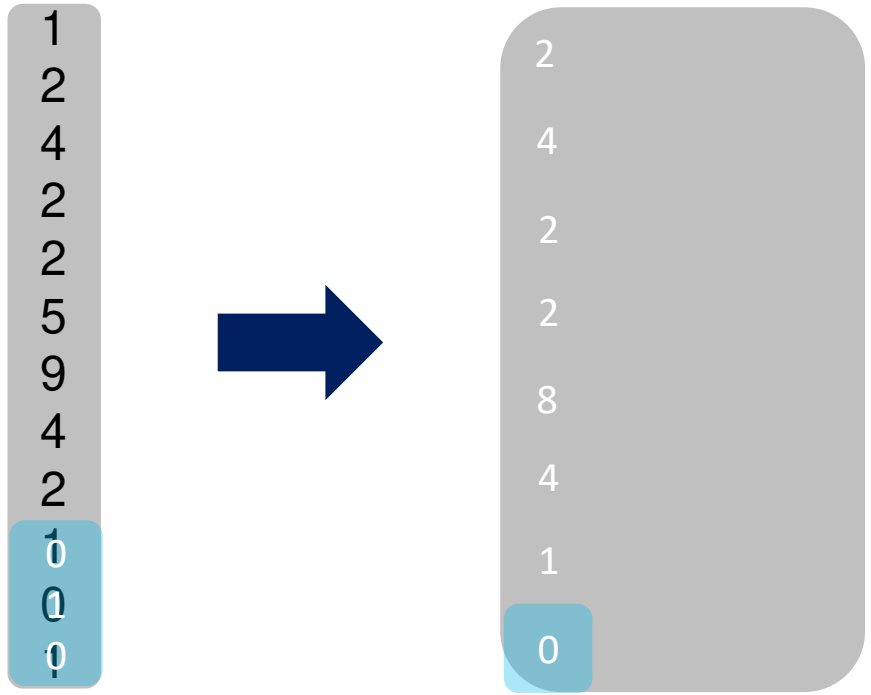


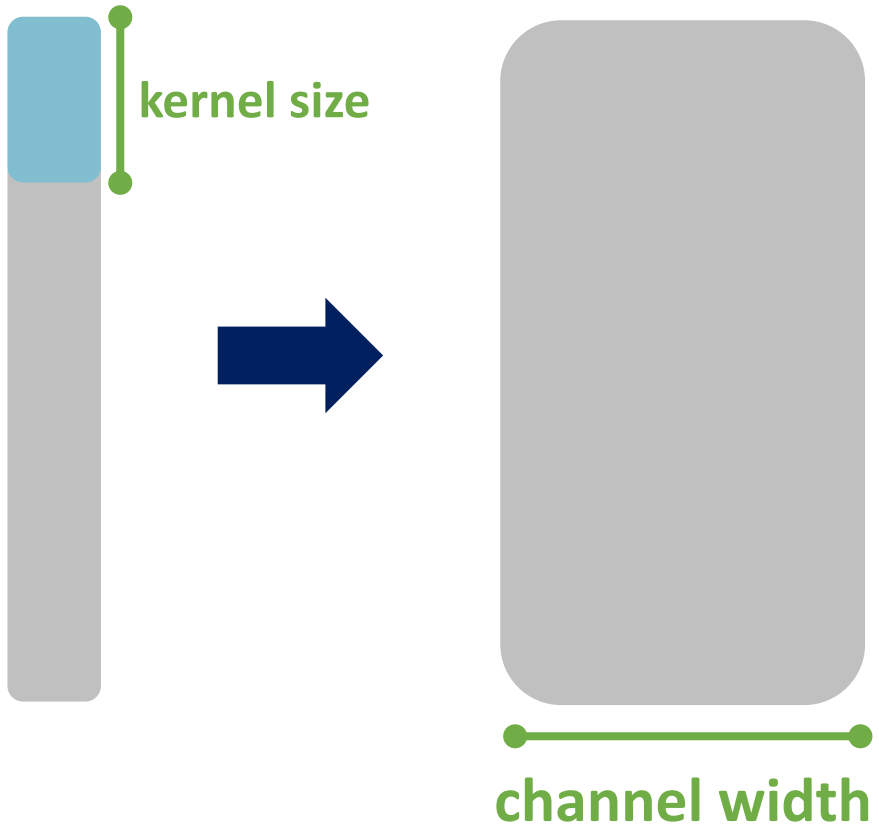
➡ Convolution
➡ Pooling layer

U-Net: Convolutional block



Convolution
Pooling layer

U-Net: Convolutional block



Convolution
Pooling layer

U-Net

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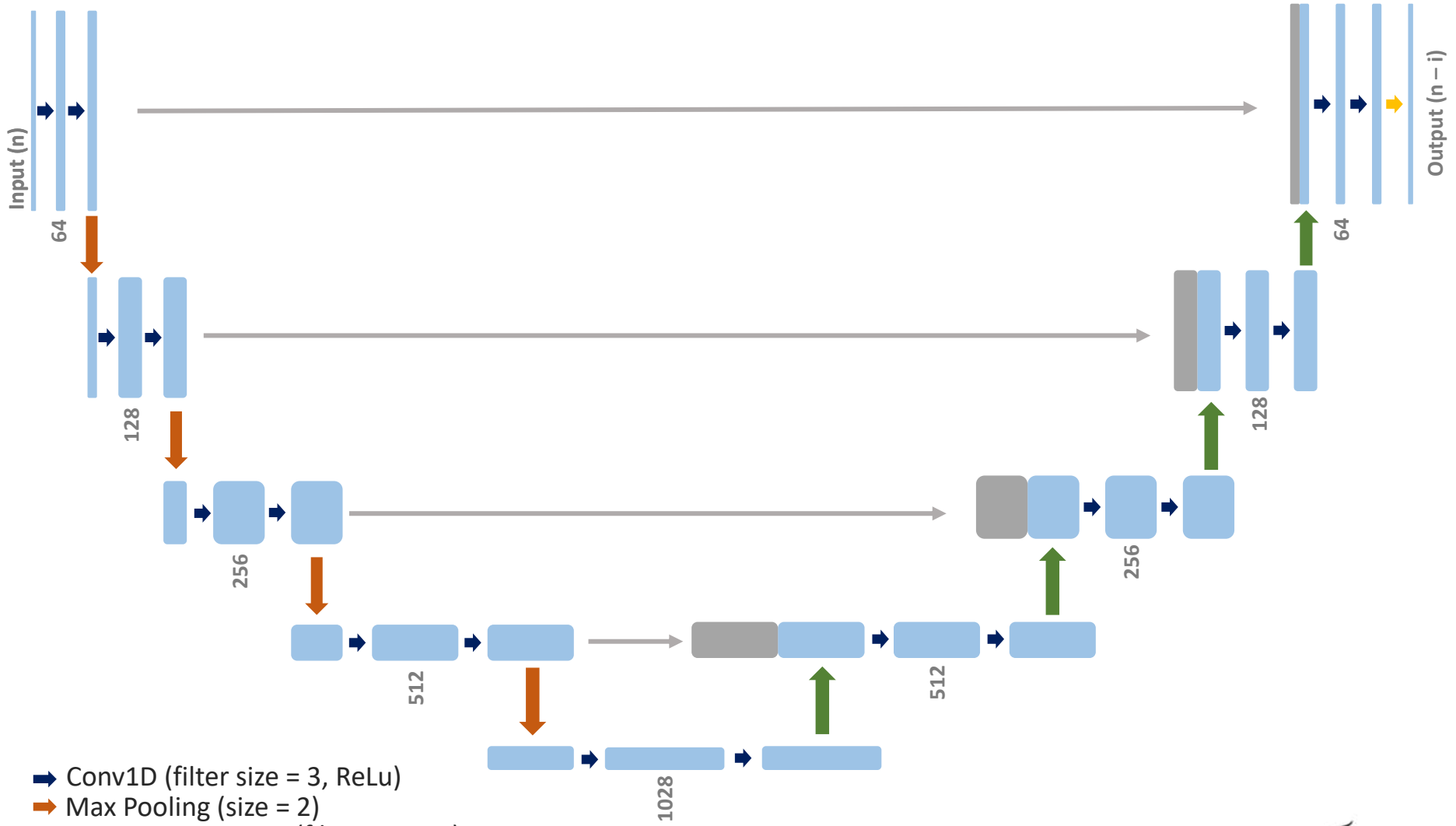

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Initial results

- Introduction
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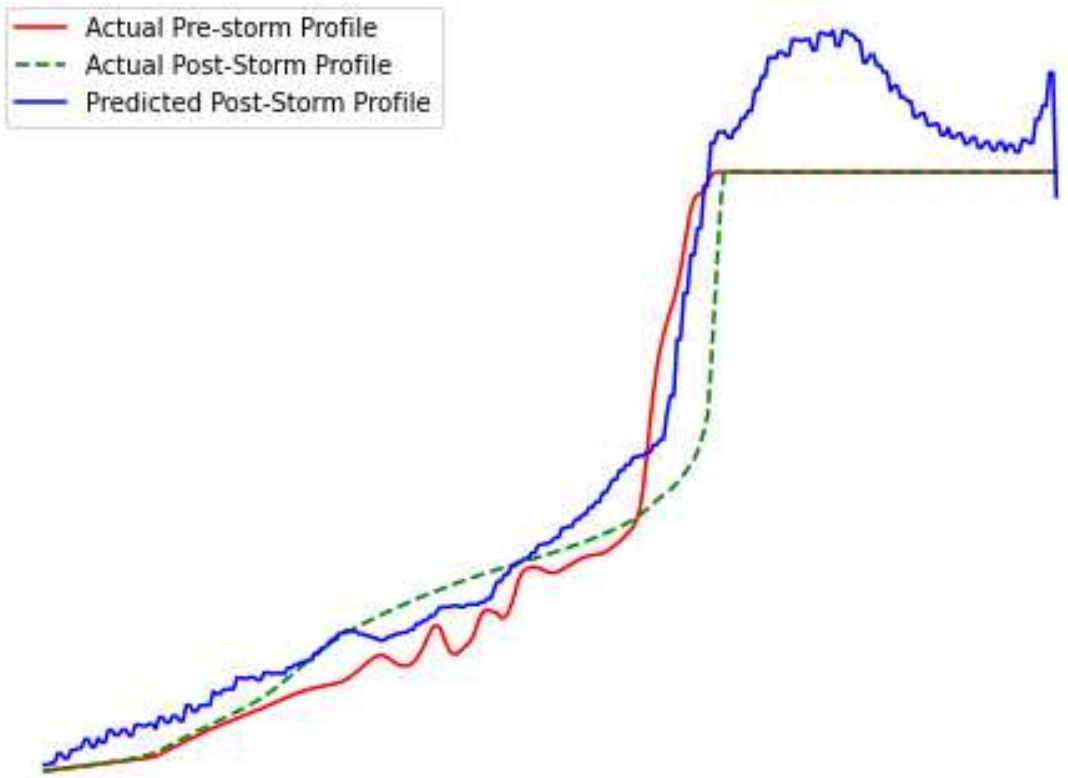

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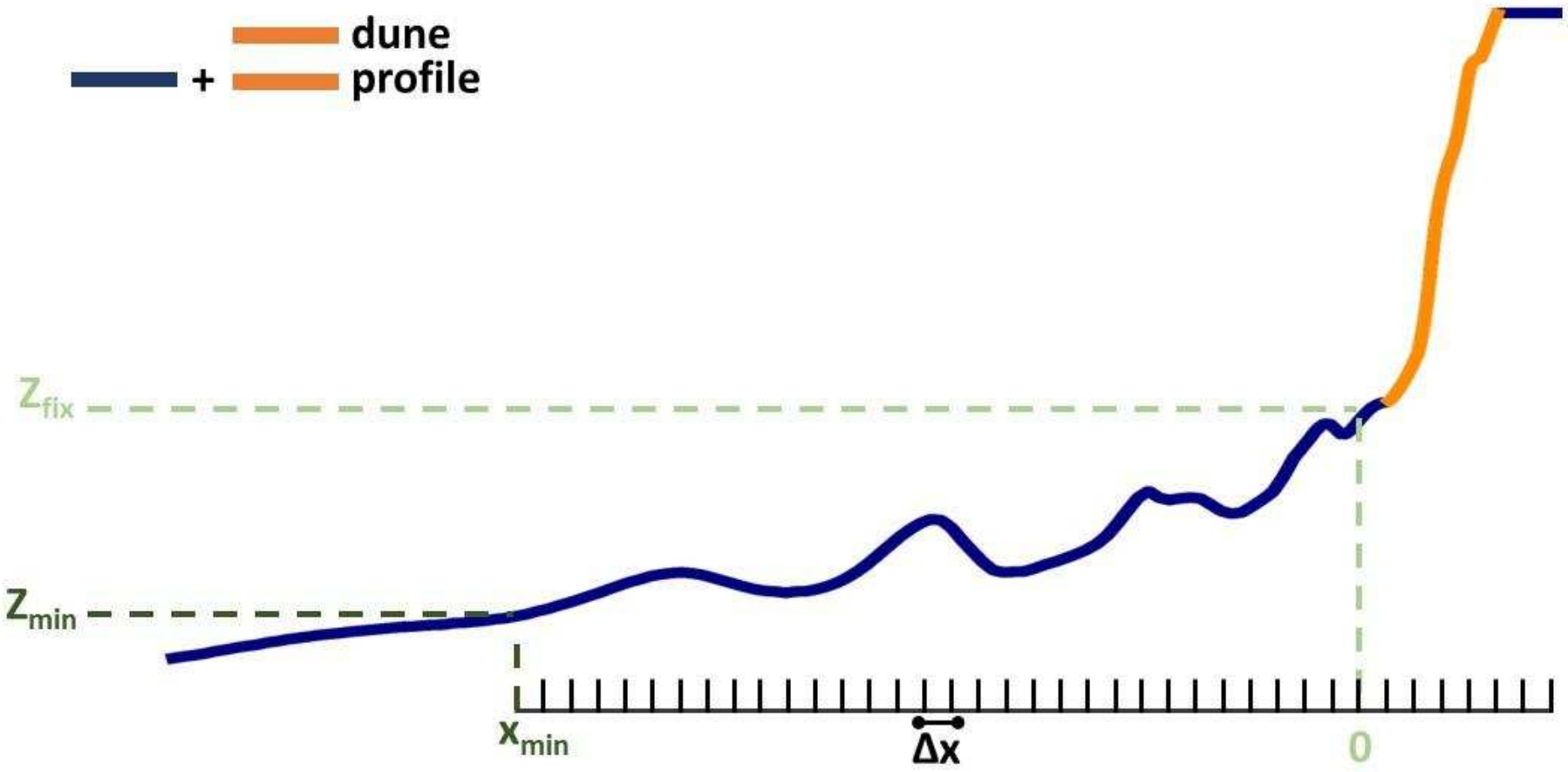
Grid standardization



Performance metric

- Introduction
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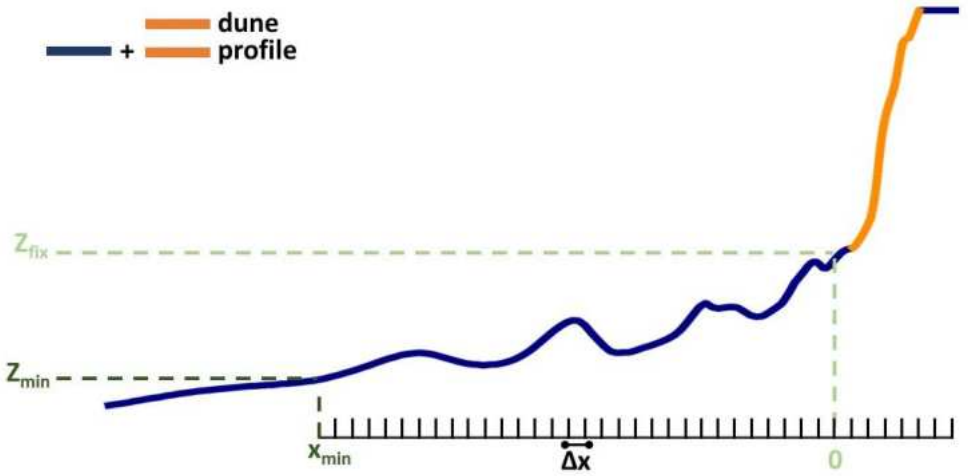
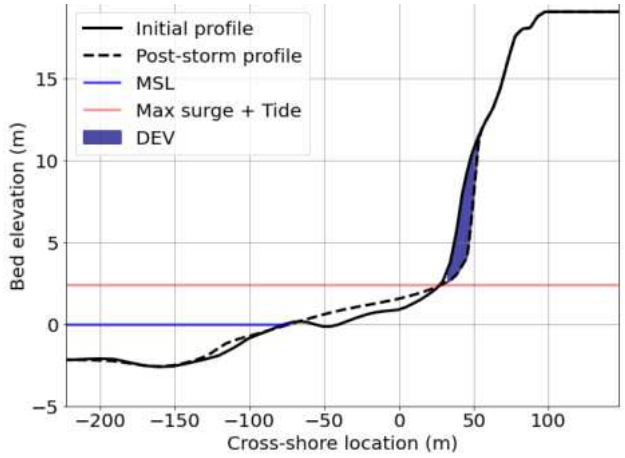
$$MSE_{dune} = \frac{1}{m}\sum(y_n - \hat{y}_n)^2$$



$$skill_{DEV} = 1 - \frac{MSE_{DEV}}{\sigma_{DEV_{target}}}$$



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Exploration: Grid standardization

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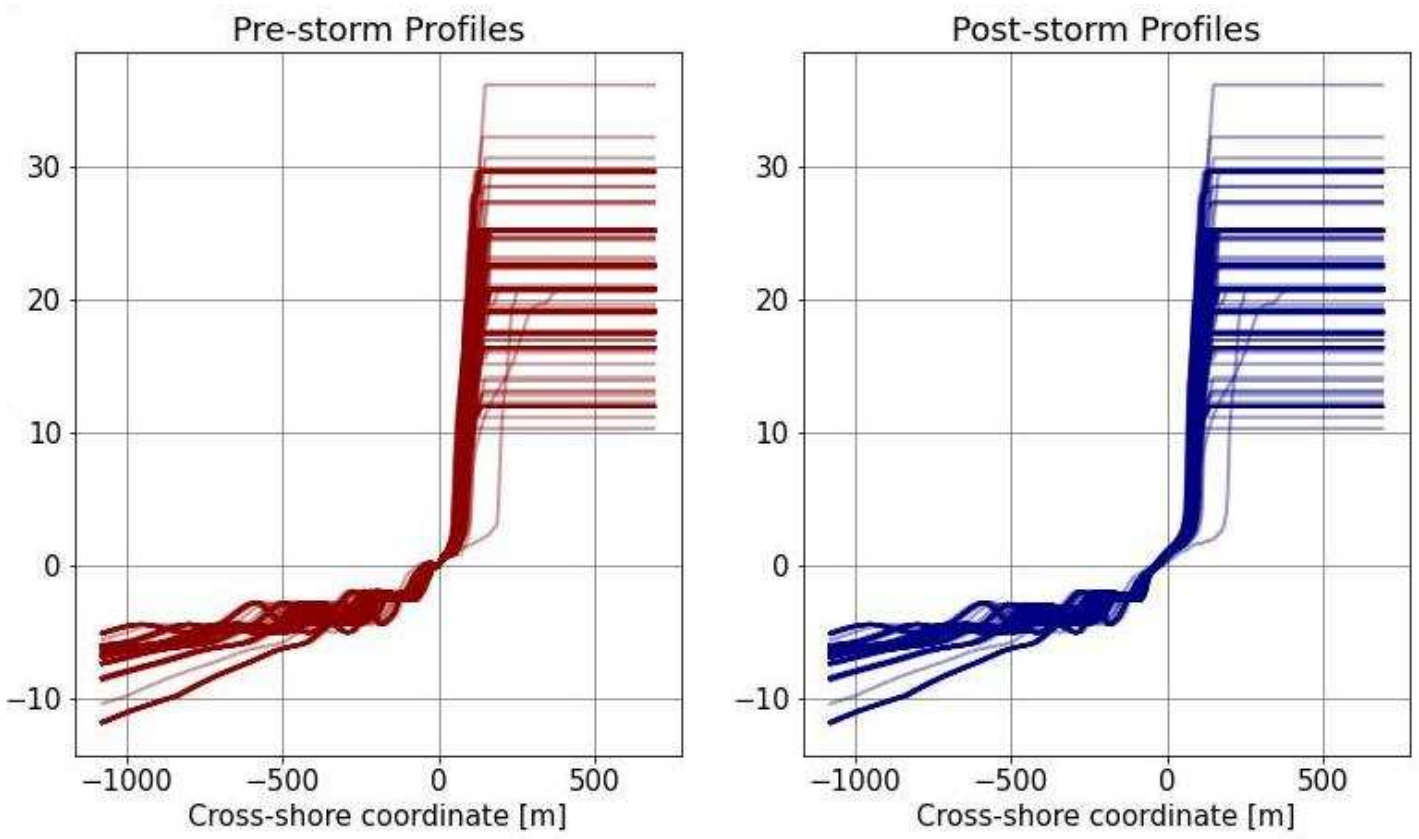

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Exploration: Difference modelling

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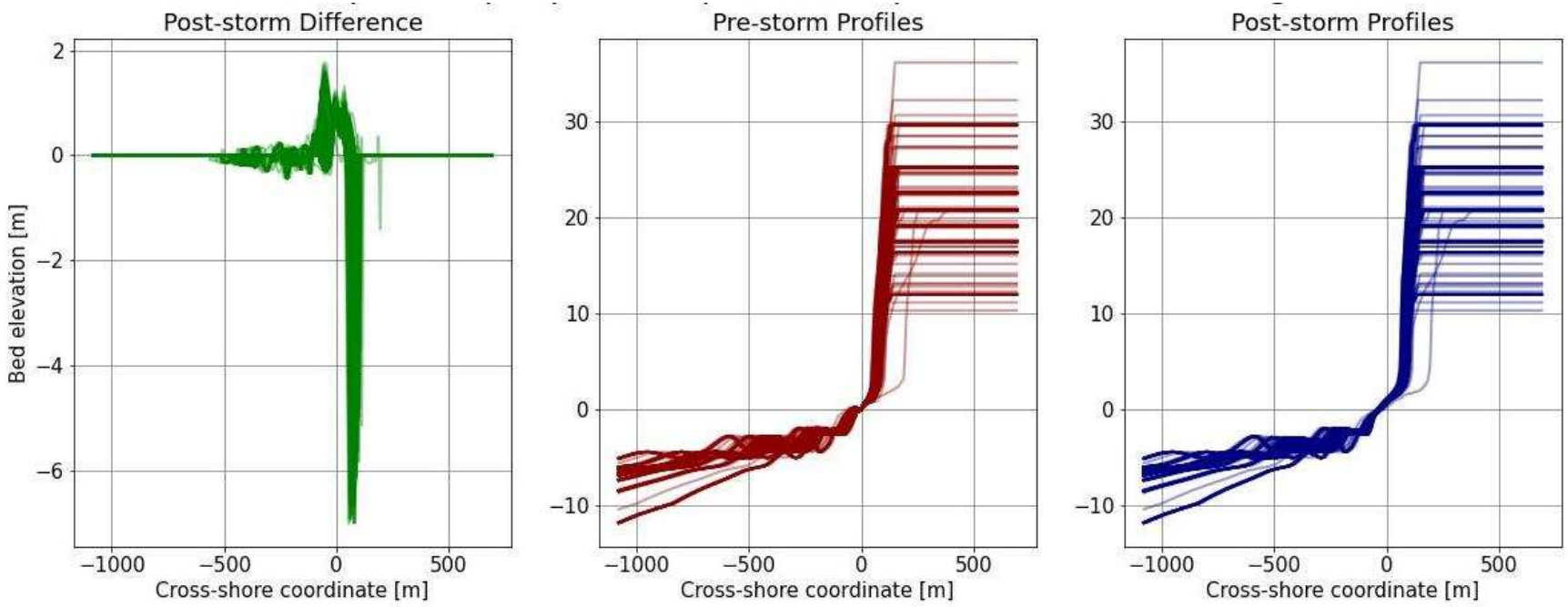

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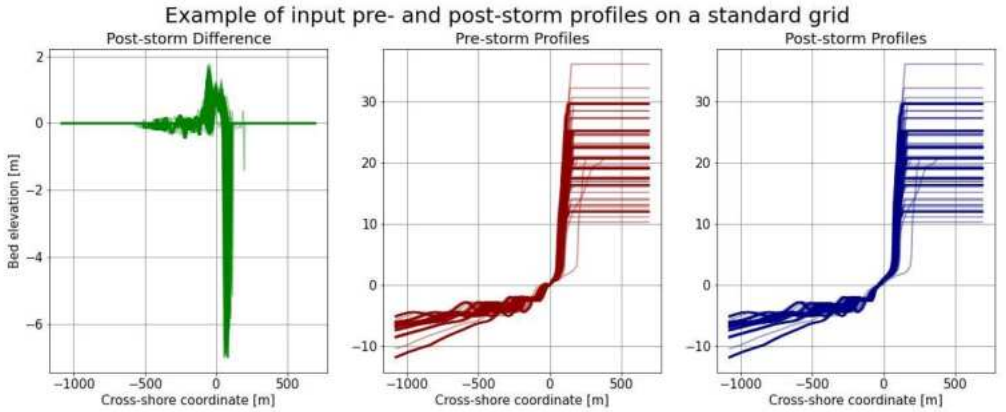
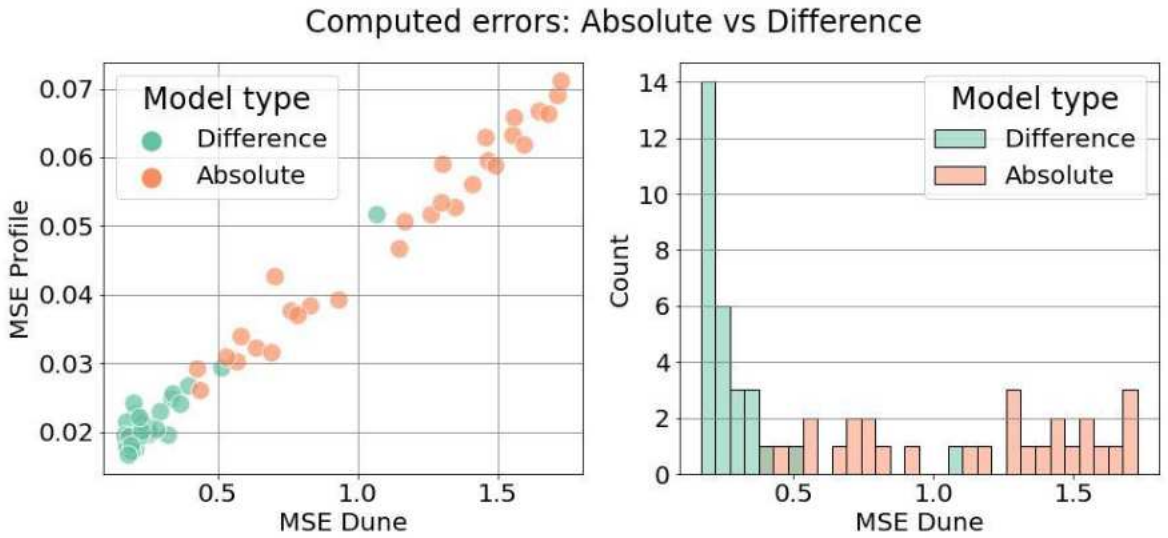
Exploration: U-Net





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Results

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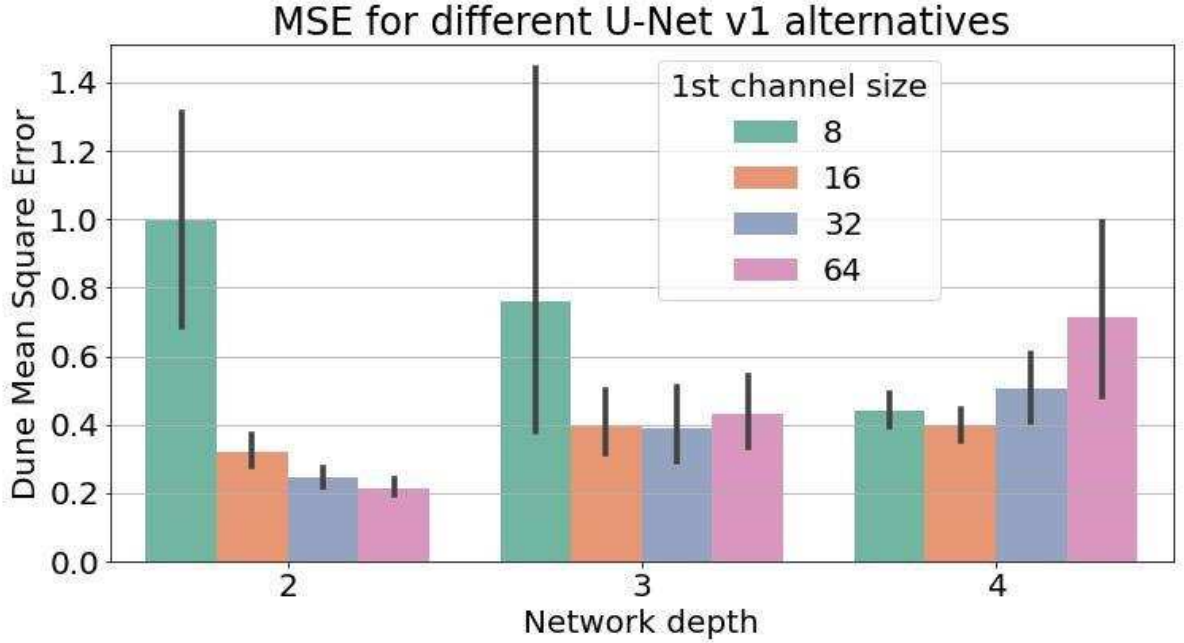

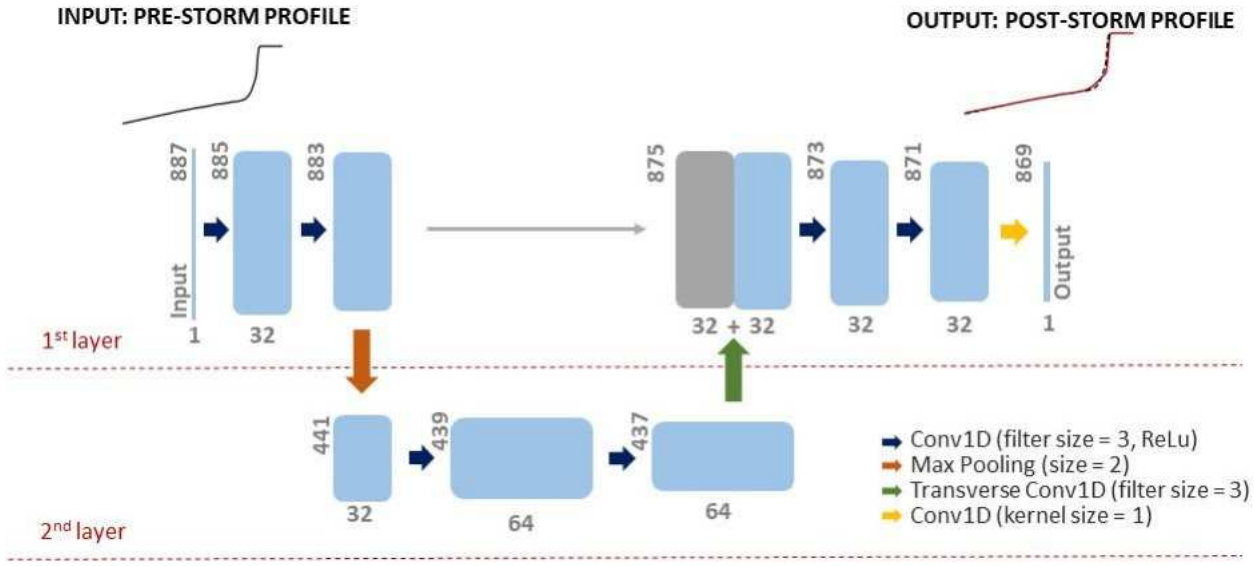

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Exploration: Results

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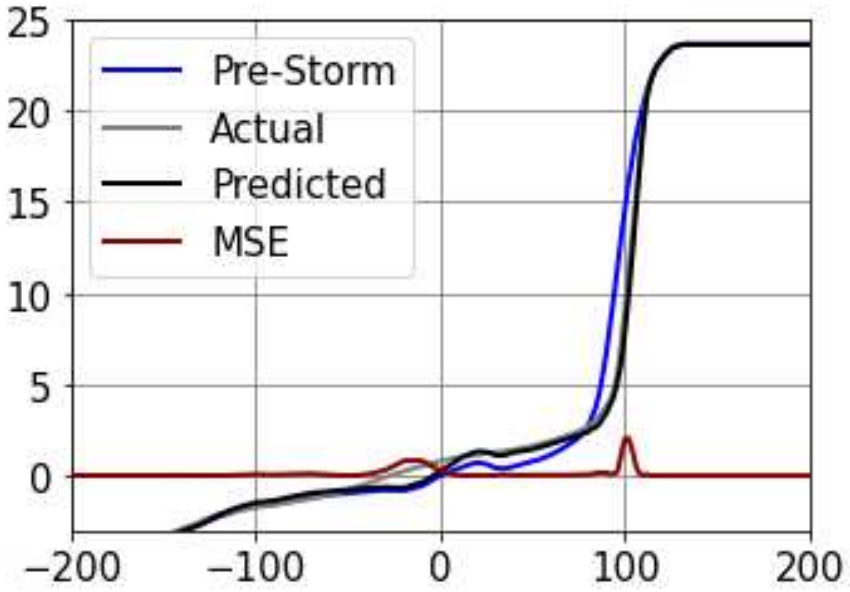

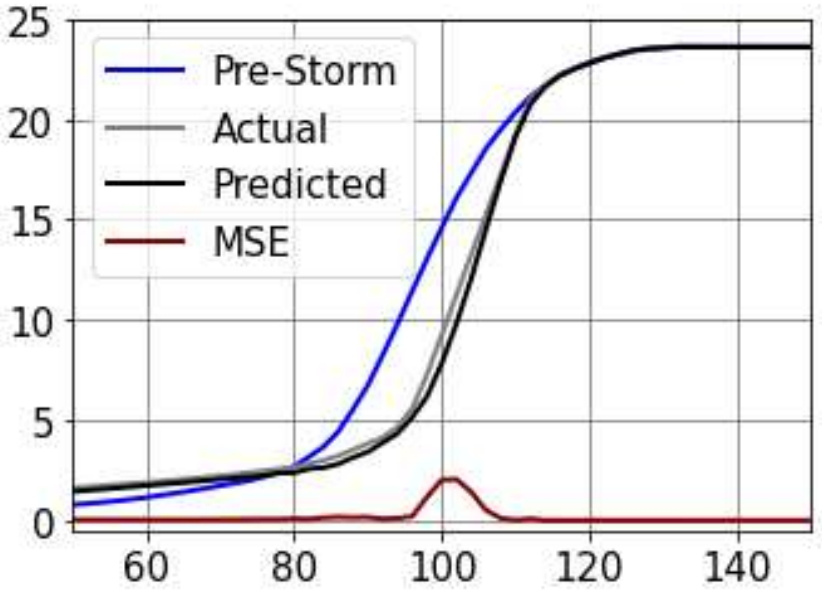

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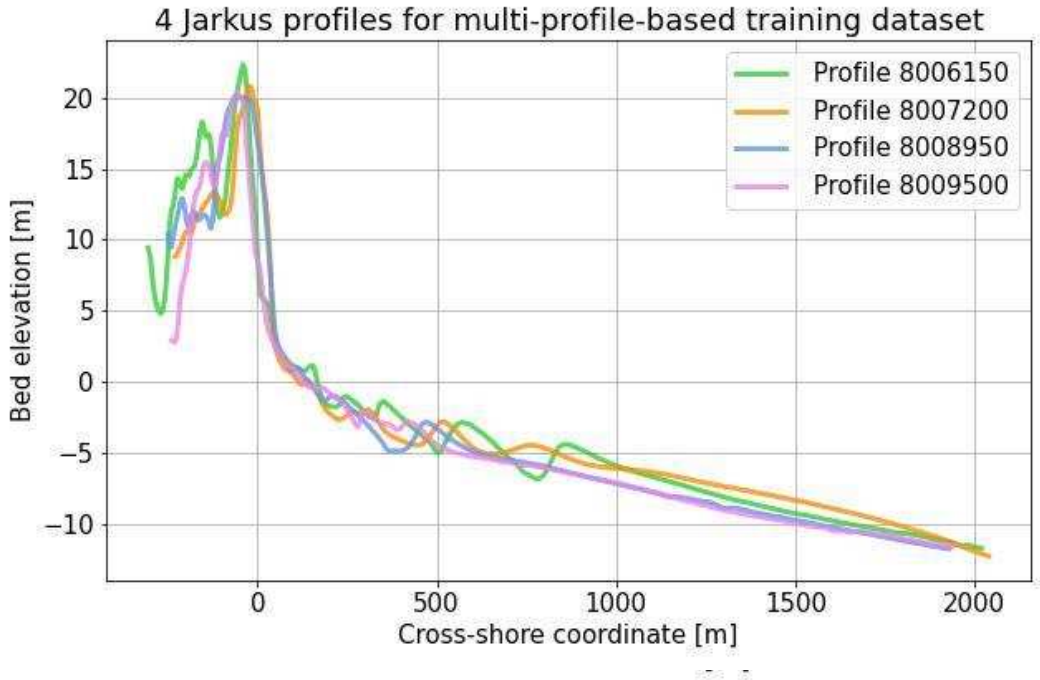
Upscaling: Training data

Multi-profile-based dataset



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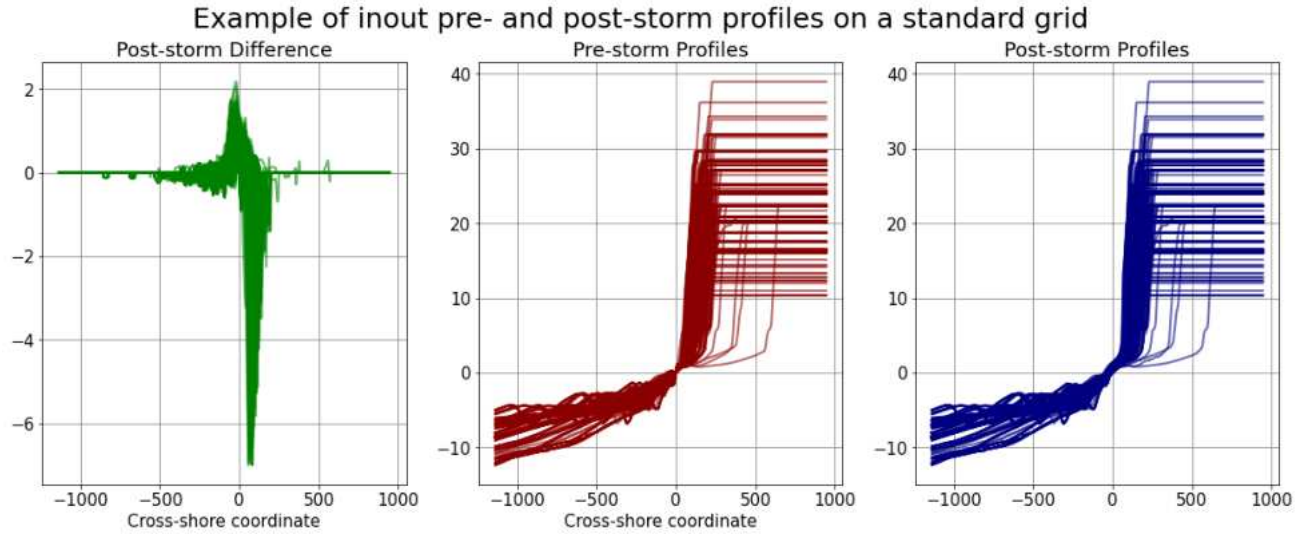
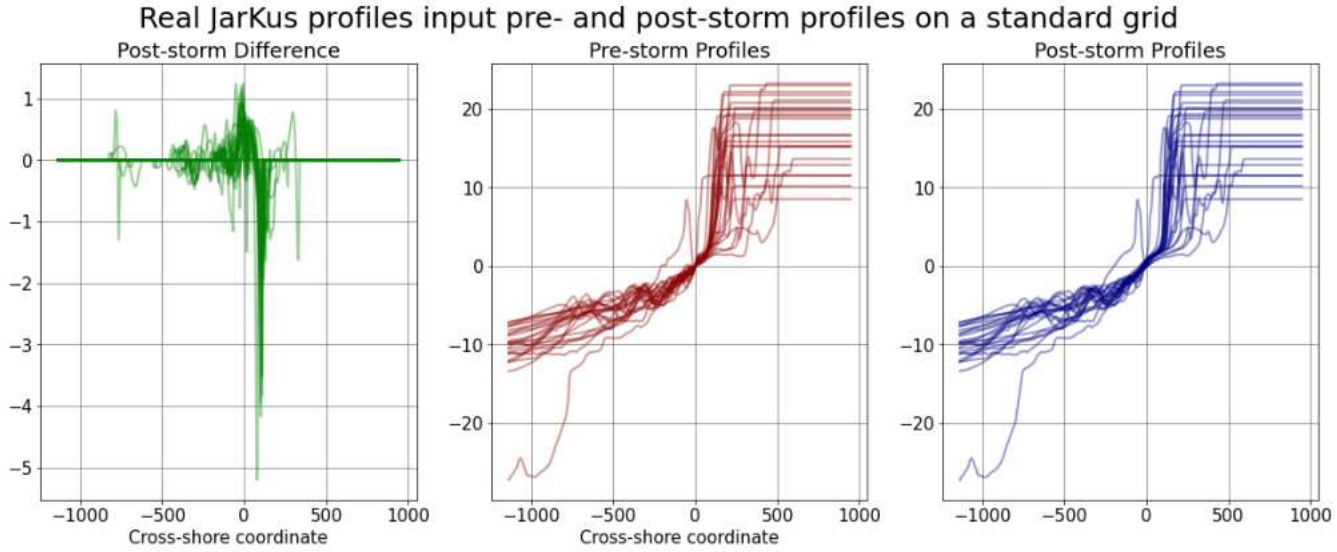
Upscaling

Training dataset
- Multi-profile-based
- 4 profiles base profiles
- 404 modified profiles

Test dataset
- Holland coast profiles
- 21 profiles





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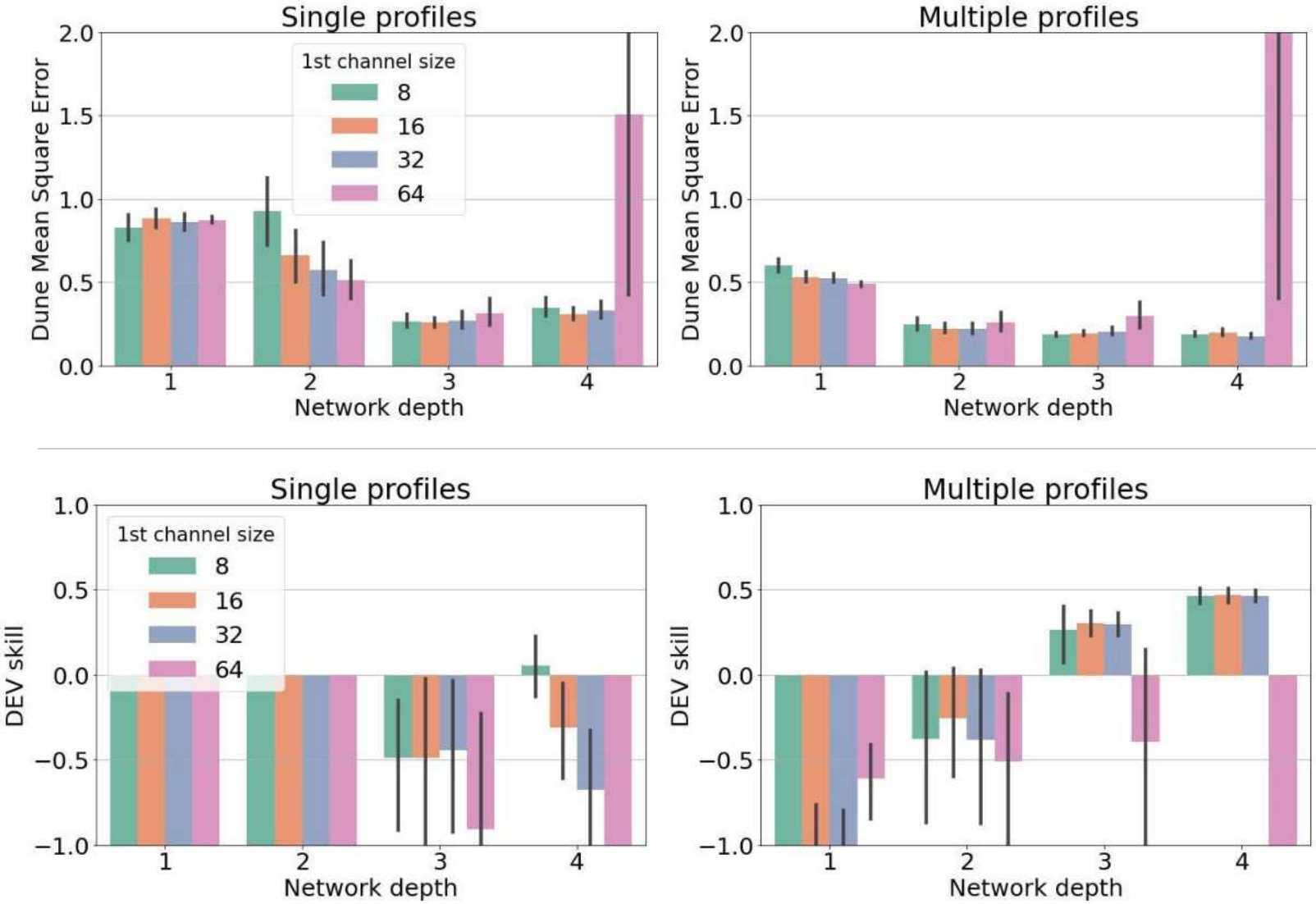
Upscaling: Network depth



Upscaling: Network depth

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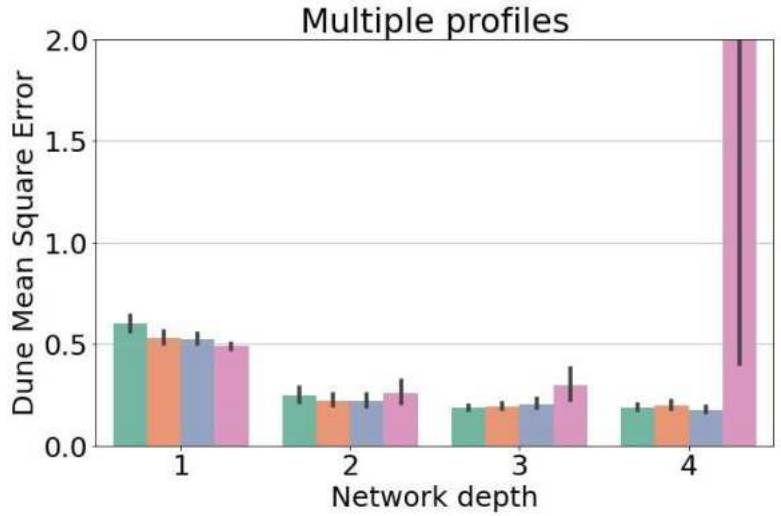

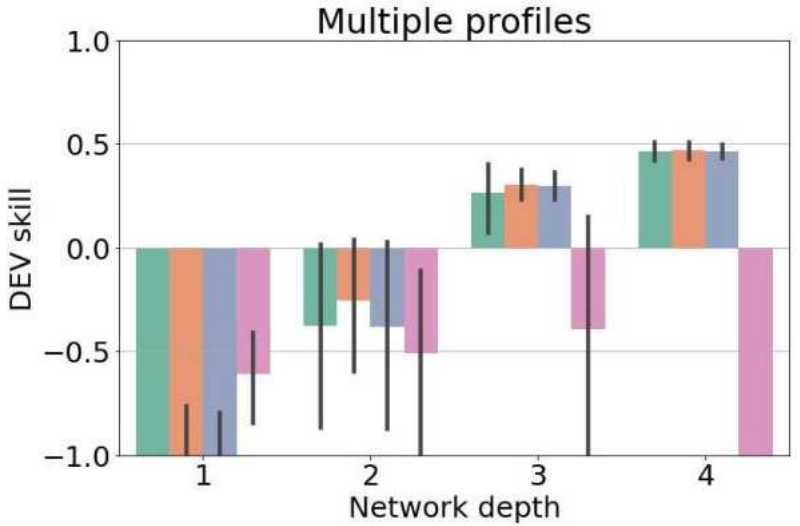

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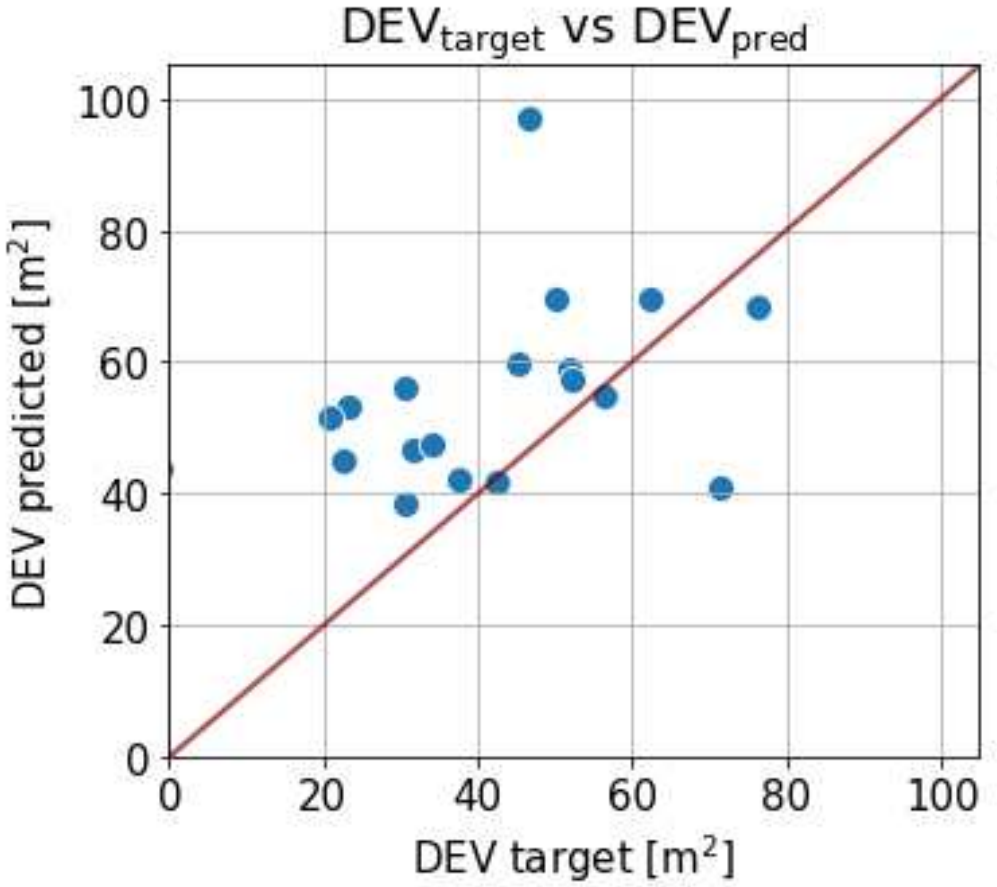
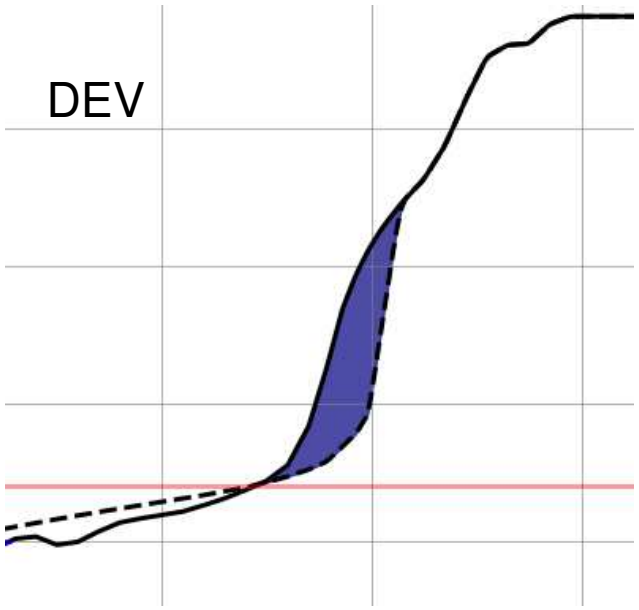
Upscaling: DEV

Network depth = 2

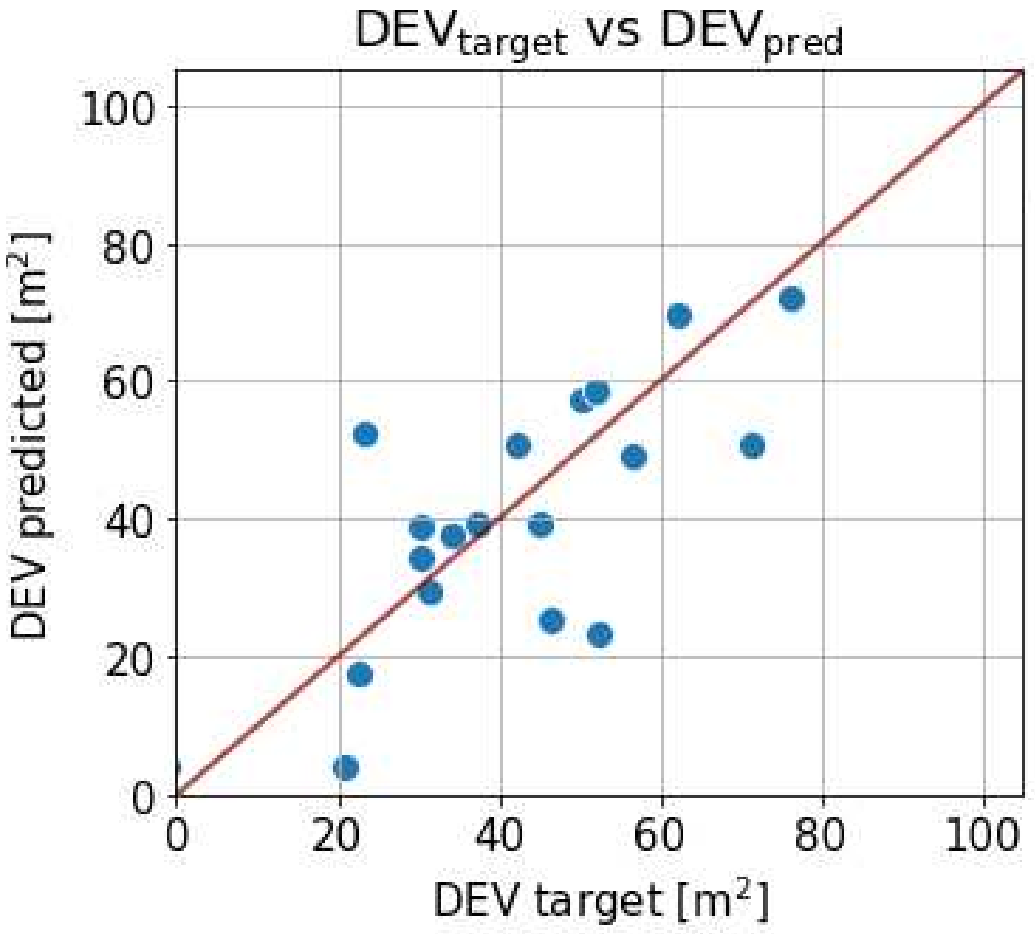


MSE$_{dune}$: 0.22
skill$_{DEV}$: -0.43

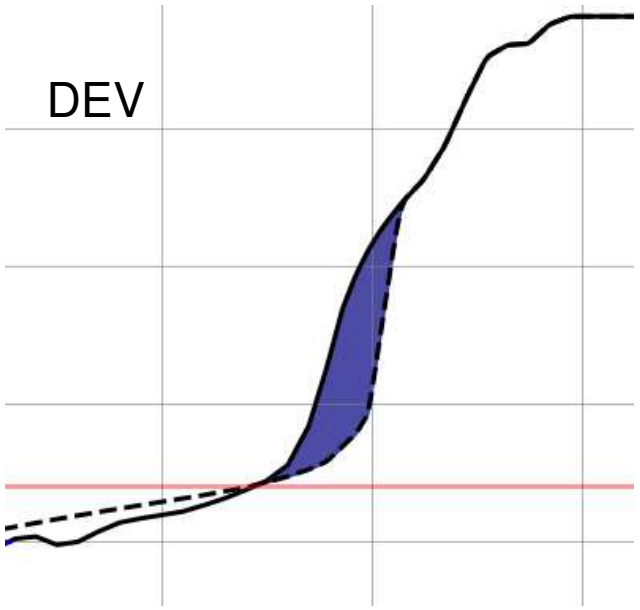


Upscaling: DEV

Network depth = 4



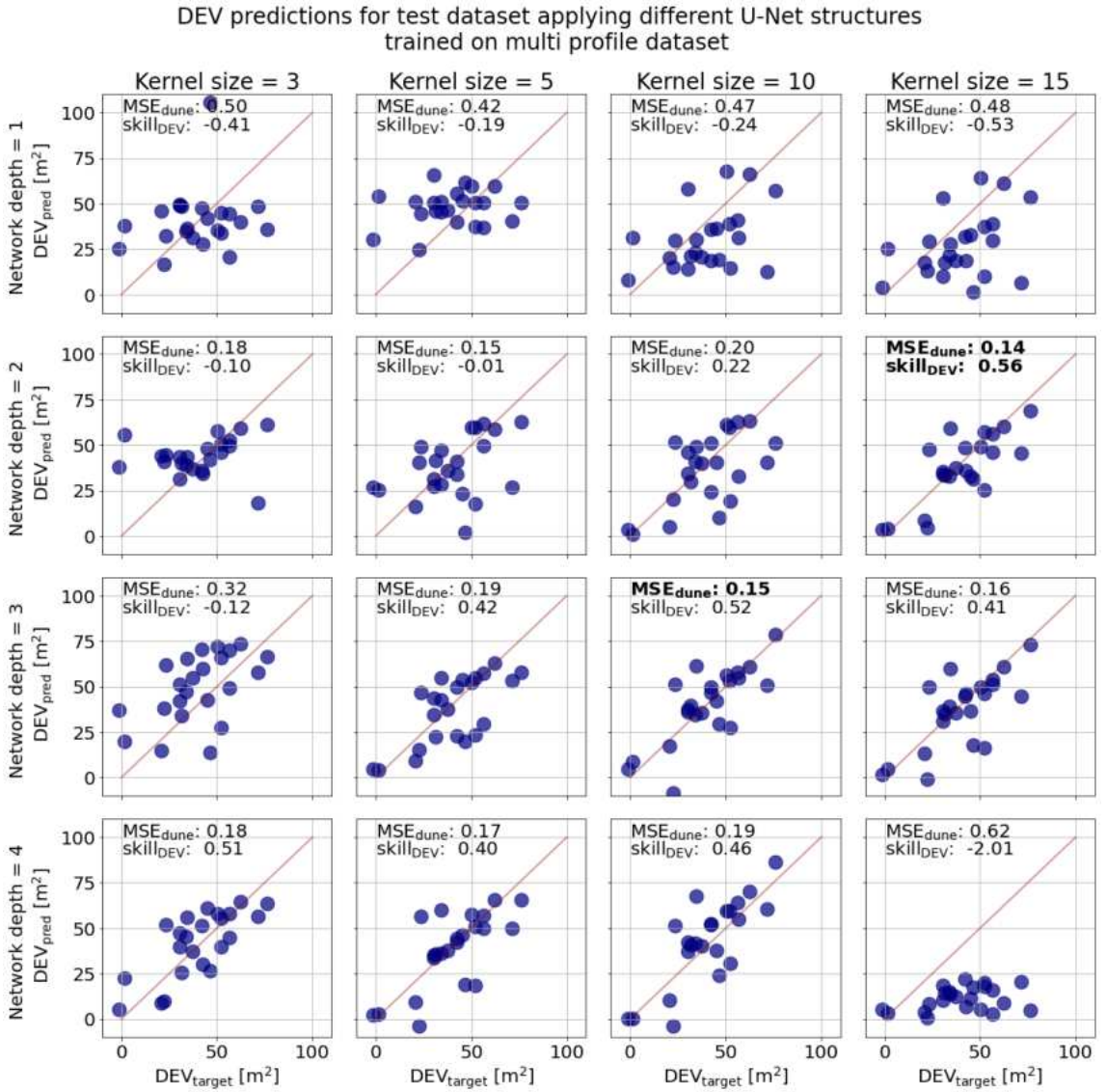
MSE_{dune}: 0.16
$skill_{DEV}$: 0.51



Upscaling: Network structure

kernel size

network depth



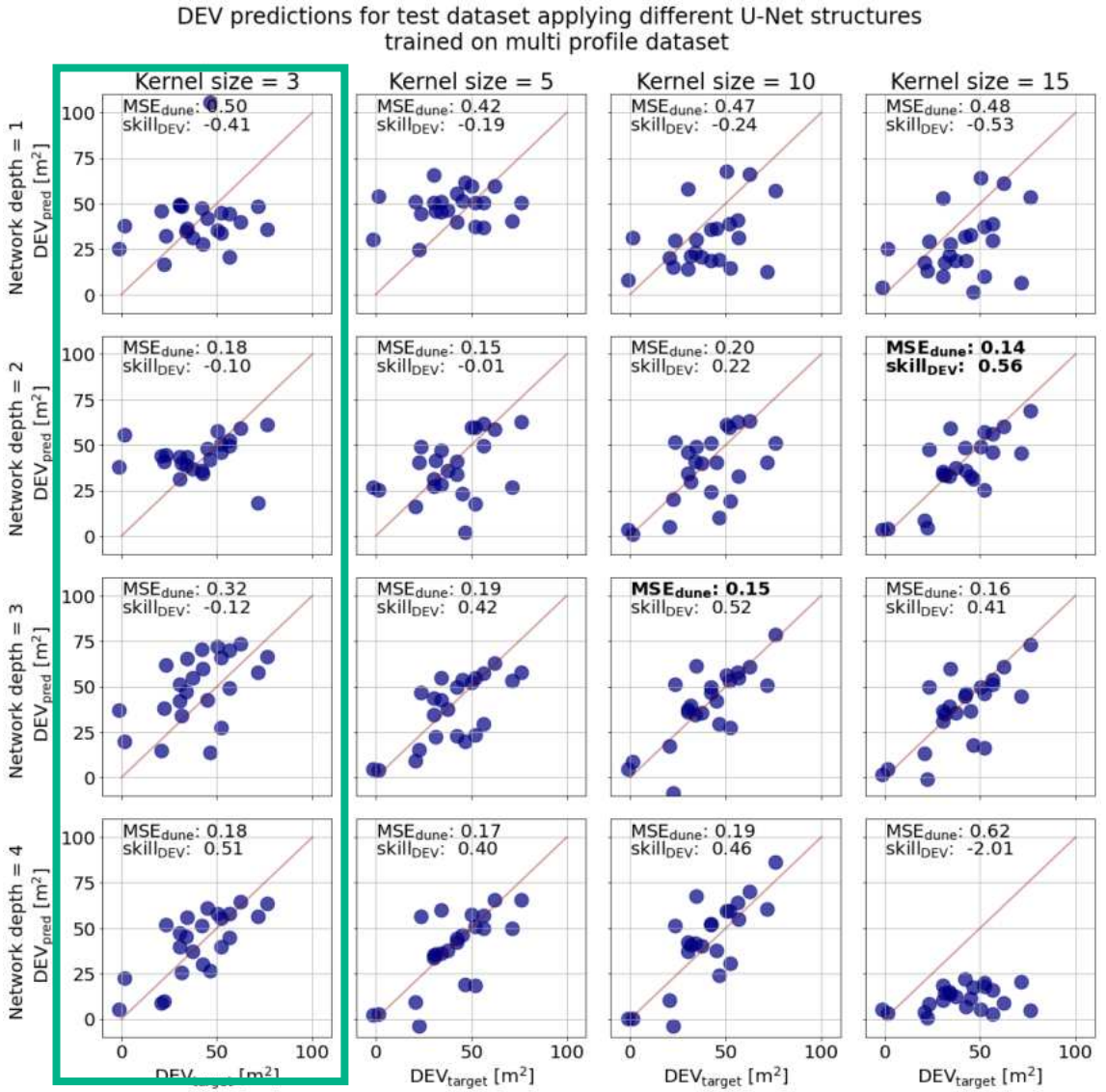
Deltares

TU Delft

Upscaling: Network structure

kernel size

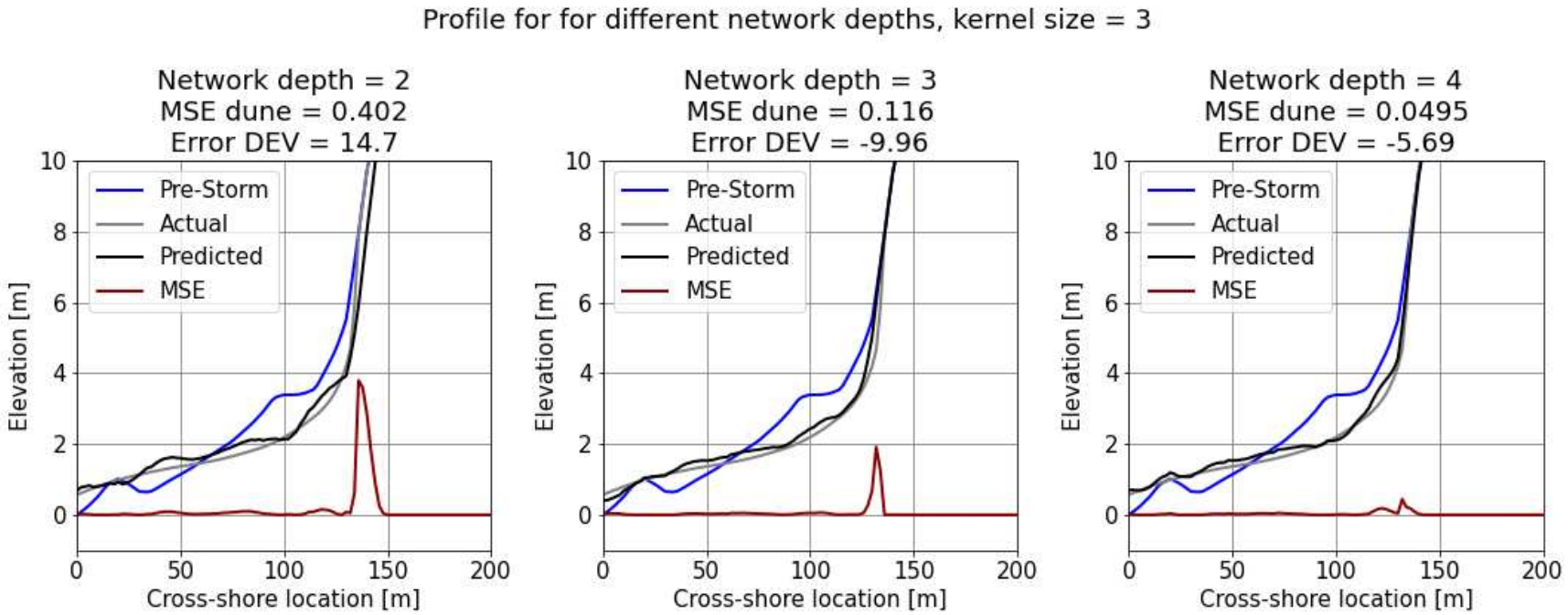
network depth



Deltares

TU Delft

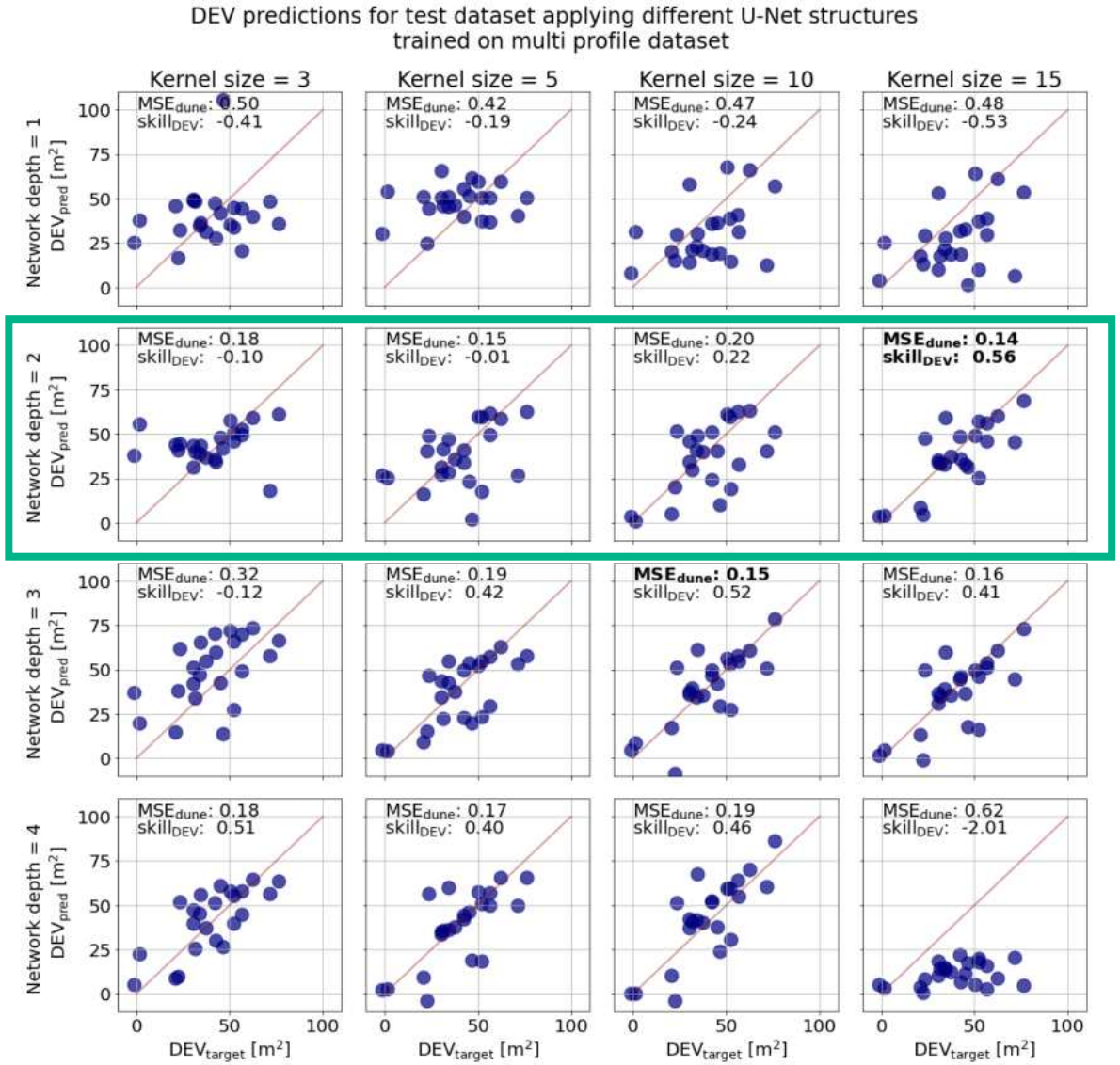
Upscaling: Detailed results



Upscaling: Network structure

kernel size

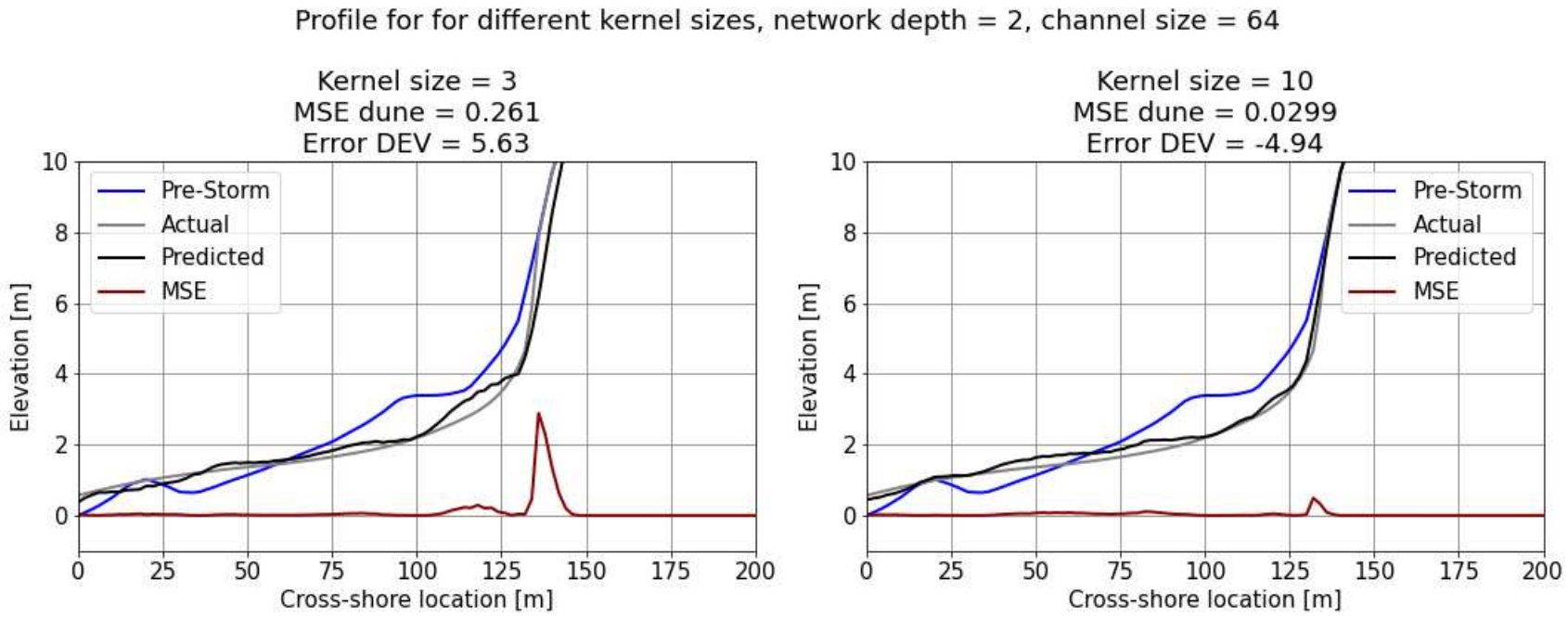
network depth



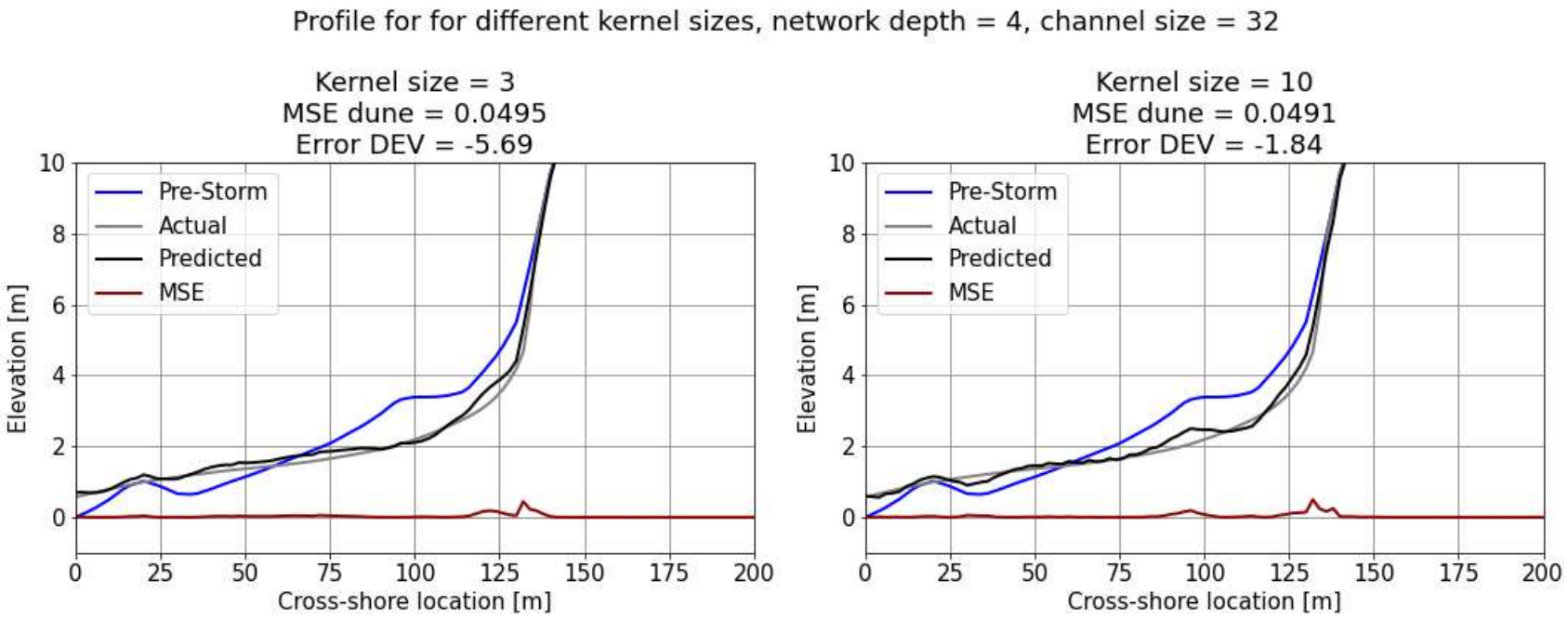
Deltares

TU Delft

Upscaling: Detailed results

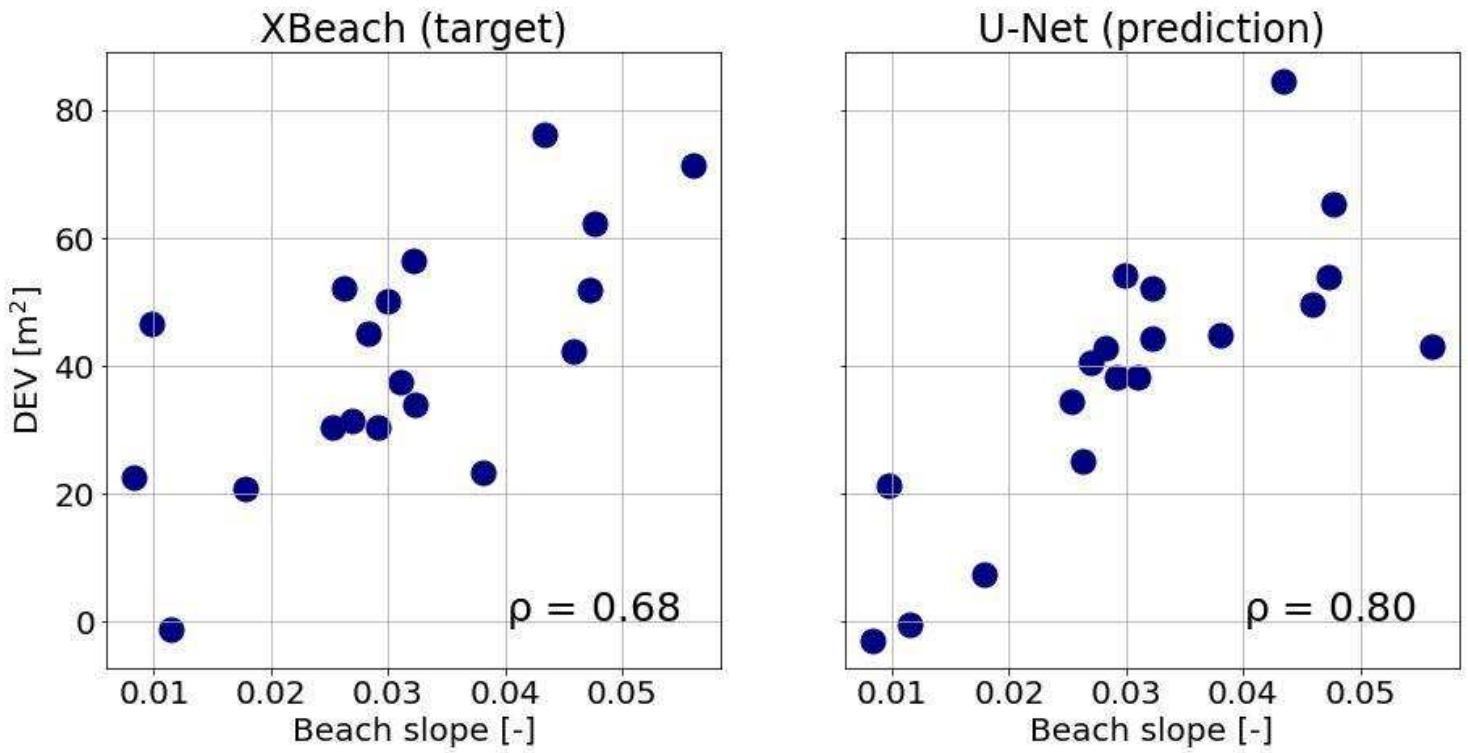


Upscaling: Detailed results



Upscaling: Mimic dune erosion

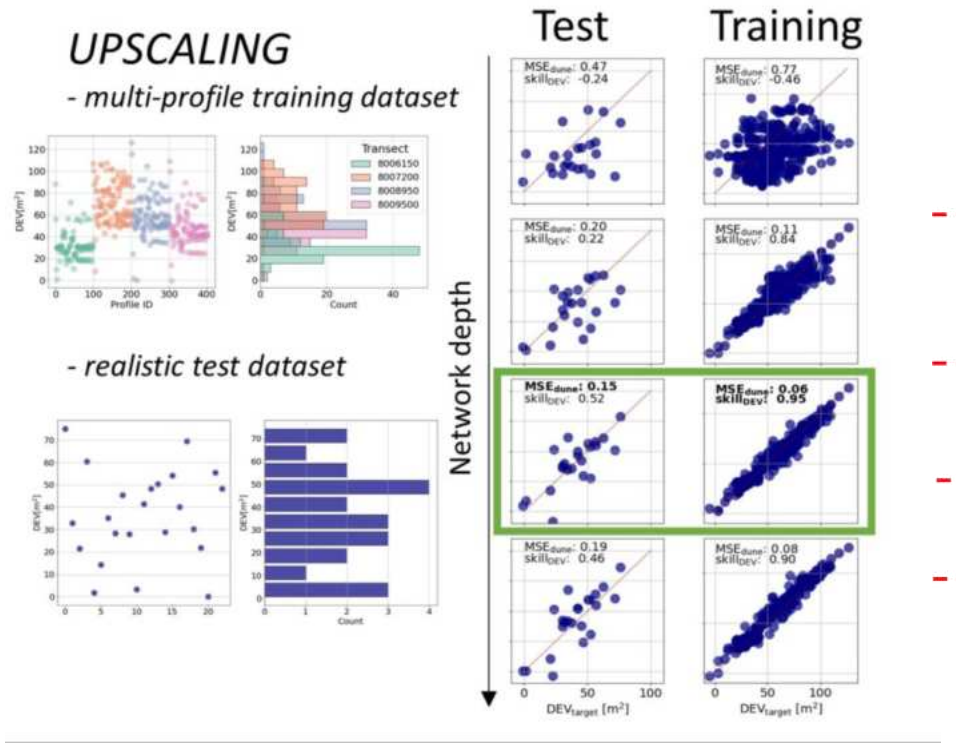
- Introduction
- XBeach
- U-Net
- Exploration
- Upscaling
- Discussion
- Conclusion

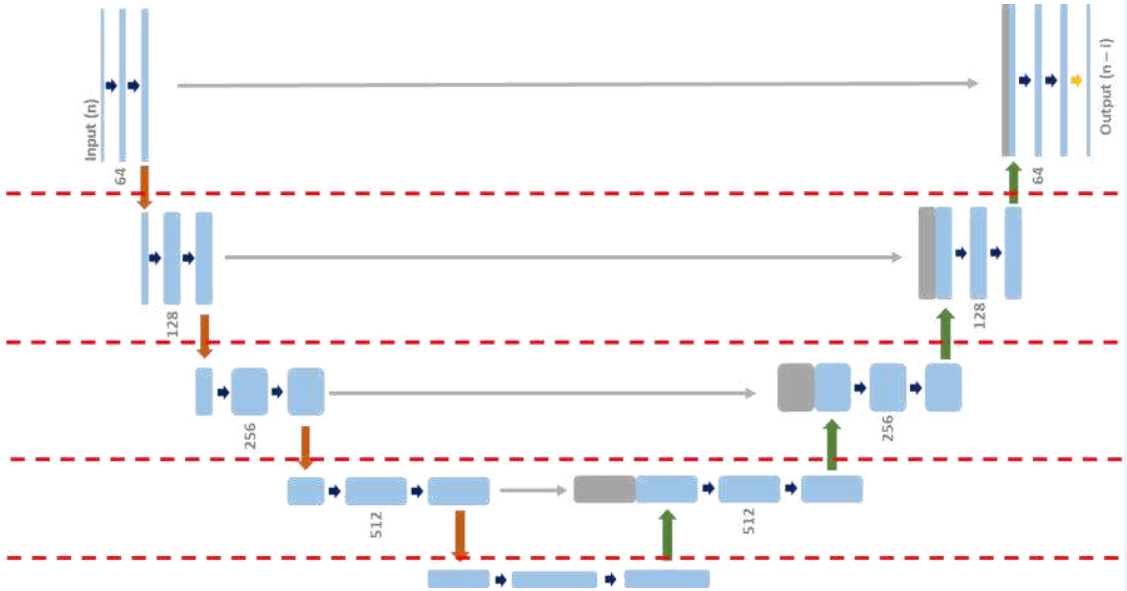


Deltares

TU Delft

Discussion: U-Net complexity



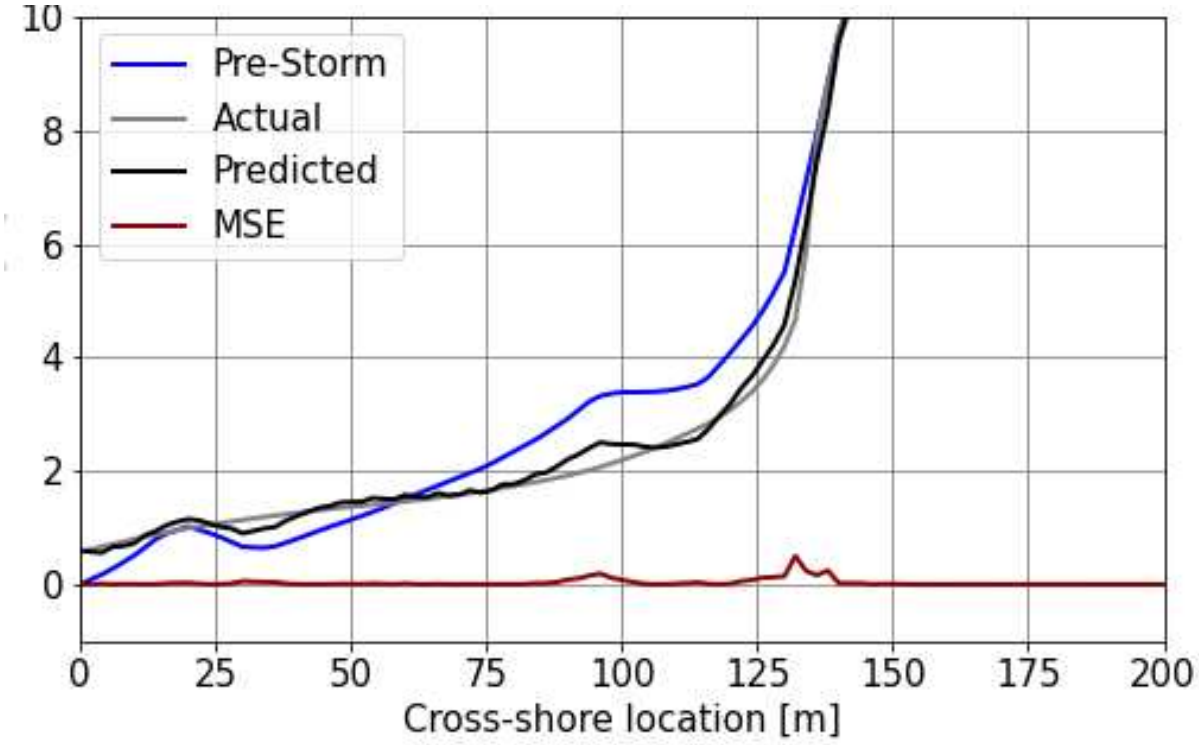


Deltares

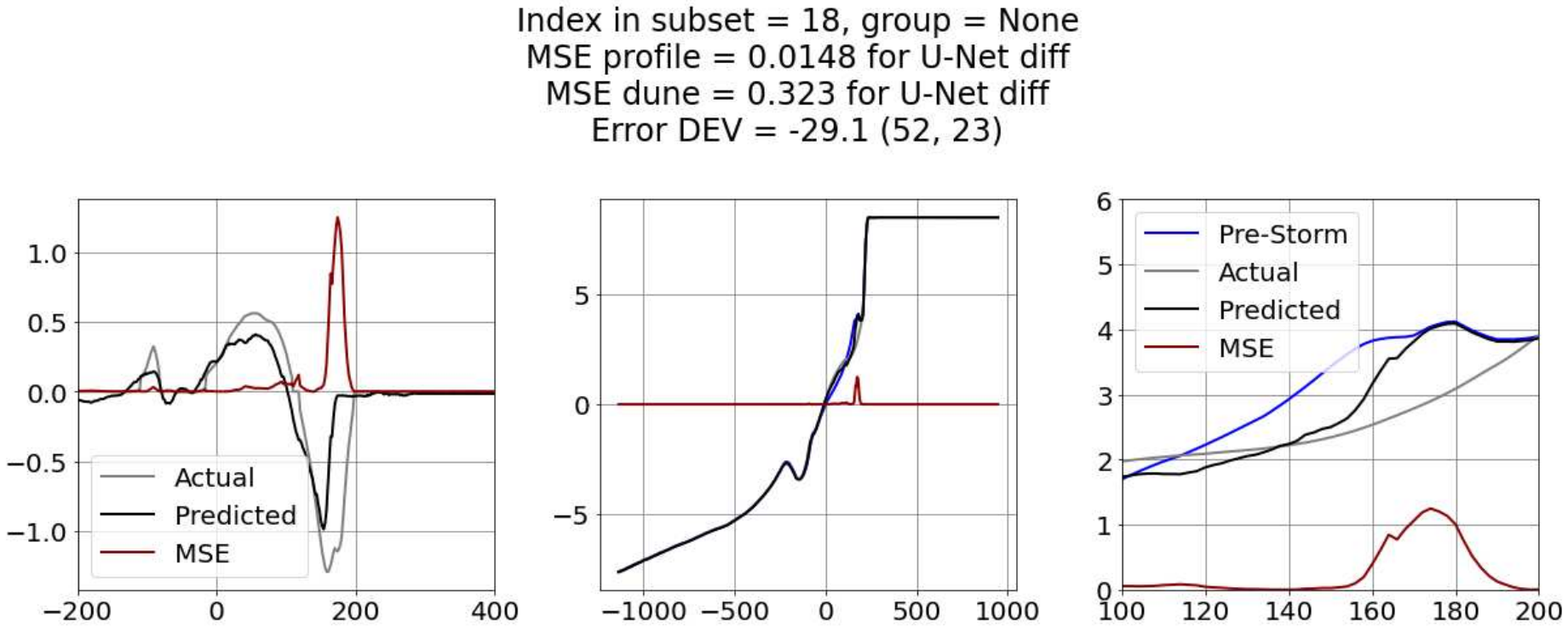
TU Delft

Discussion: Performance metric

- RMSTE
- Skill
  - Dune toe location
  - Fore dune slope
  - Dune crest height
  - Beach retreat



Discussion: Foredune shape



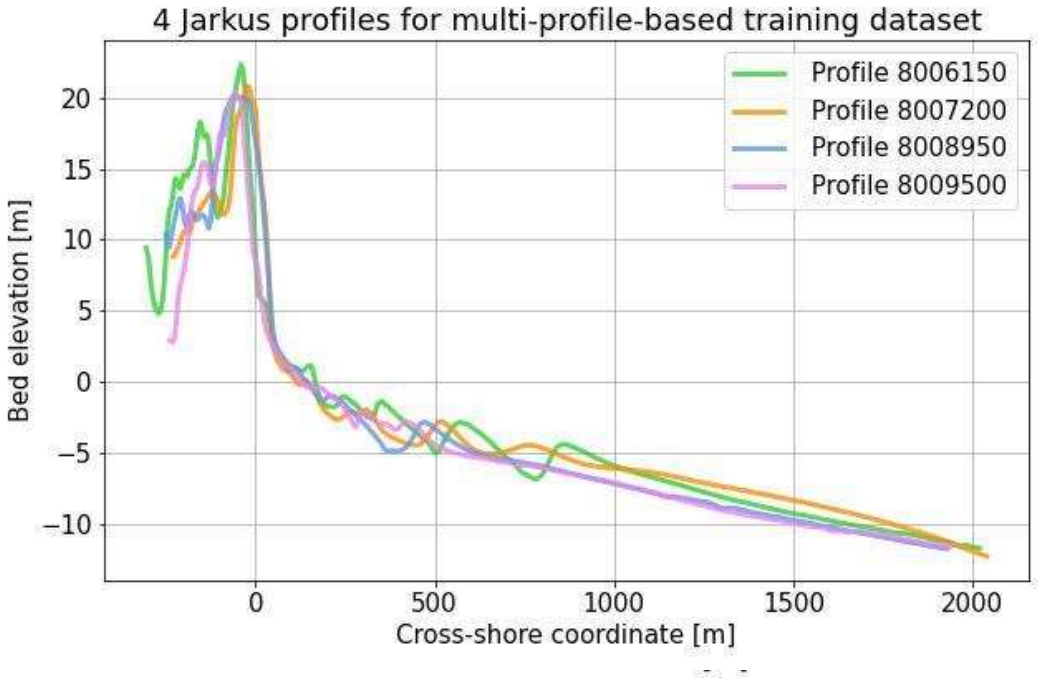
Conclusion

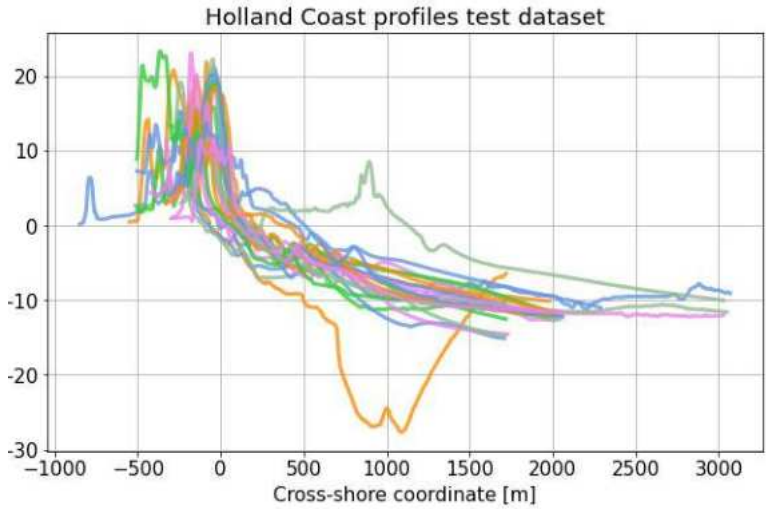
Can neural networks be used for predicting post-storm profiles of **actual** Holland coast profile shapes?

- Using U-Net and simplified conditions, post-storm profiles shapes can be predicted
- Can be applied to extract DEVs, which can be predicted with a skill of 0.51

Recommendations: Training data

Multi-profile-based dataset



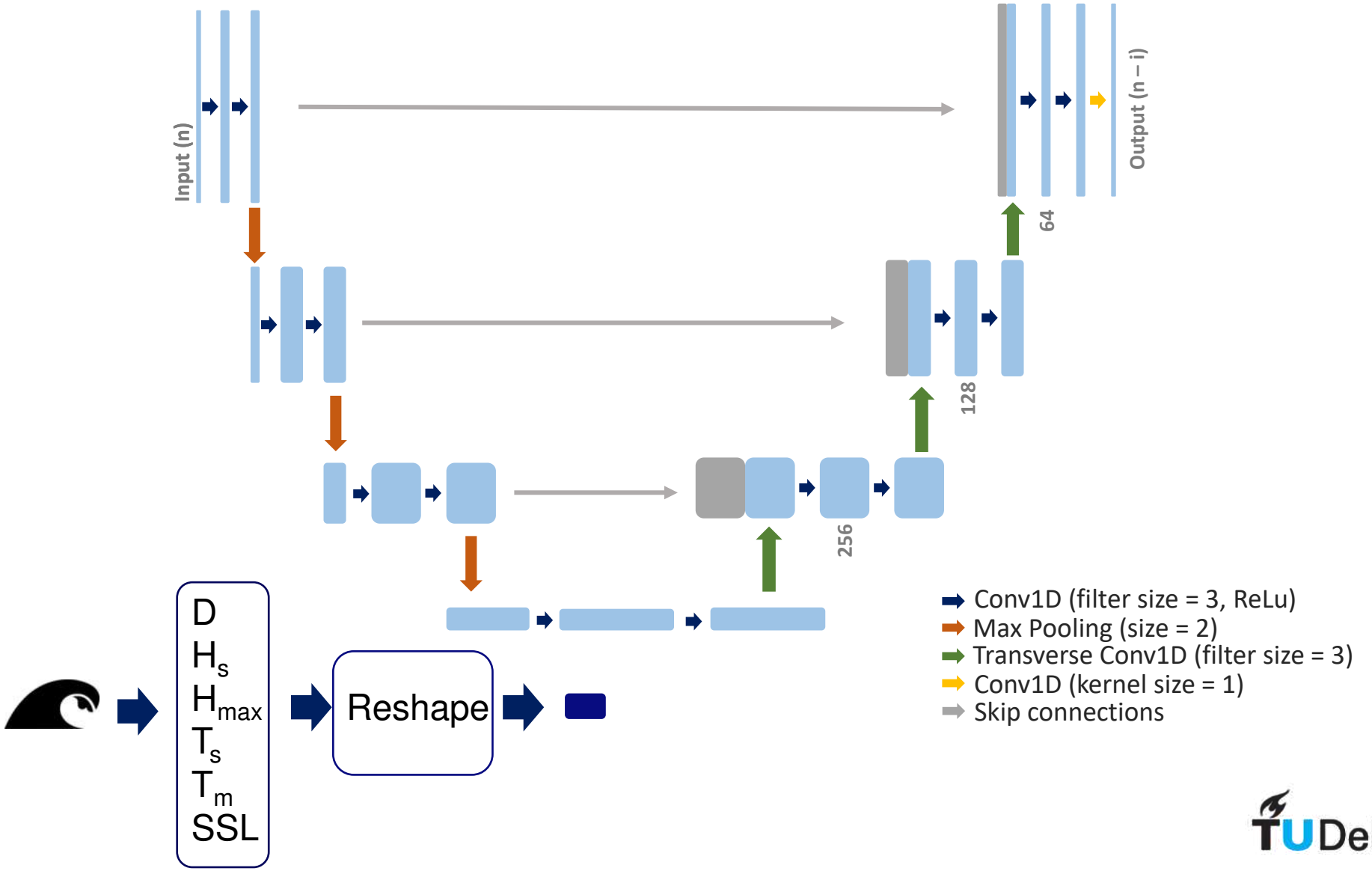


Deltares

TU Delft

Recommendations: Storm input

- Introduction
- XBeach
- U-Net
- Exploration
- Upscaling
- Discussion
- Conclusion

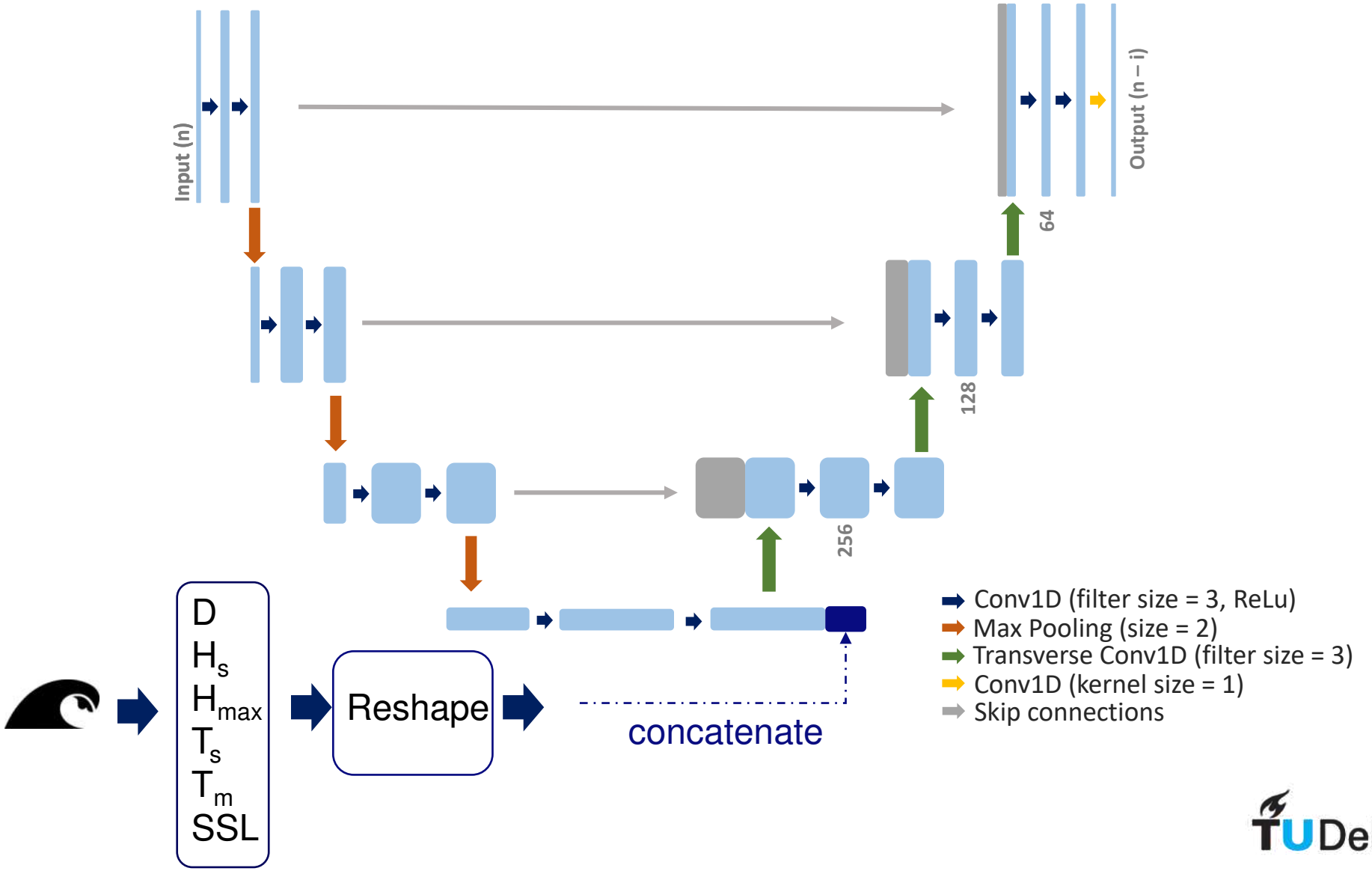


Deltares

TU Delft

Recommendations: Storm input

- Introduction
- XBeach
- U-Net
- Exploration
- Upscaling
- Discussion
- Conclusion



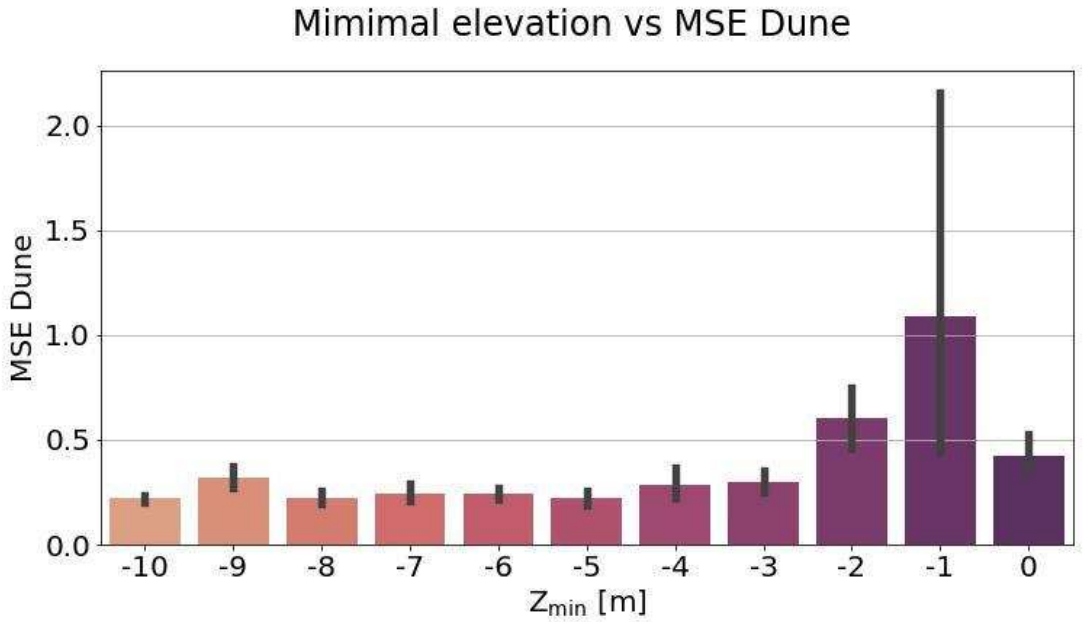
Deltares

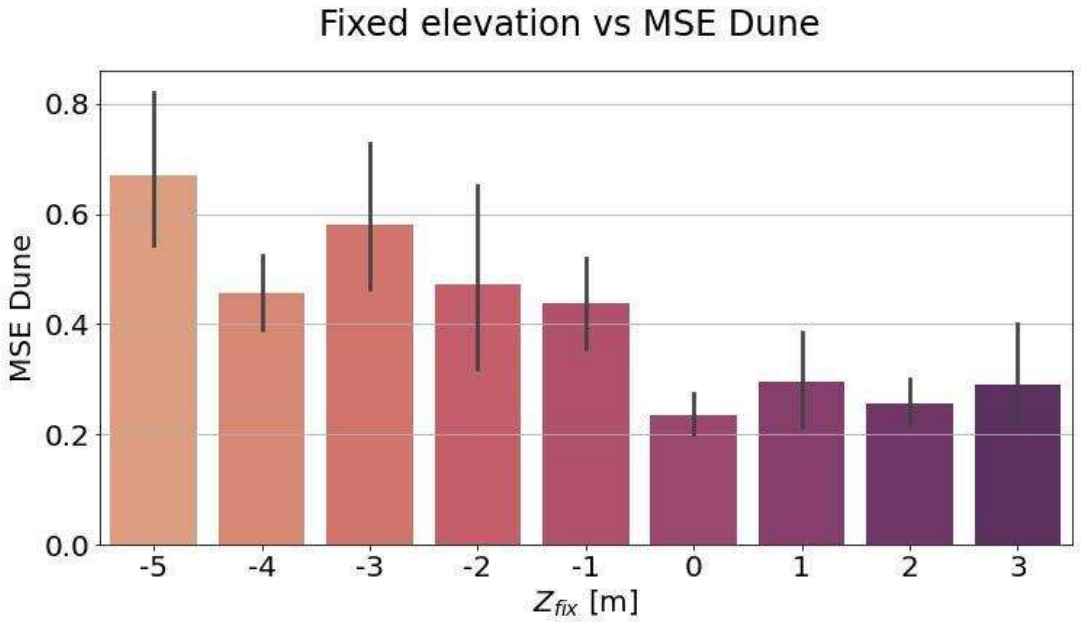
TU Delft

Thank you!

Results

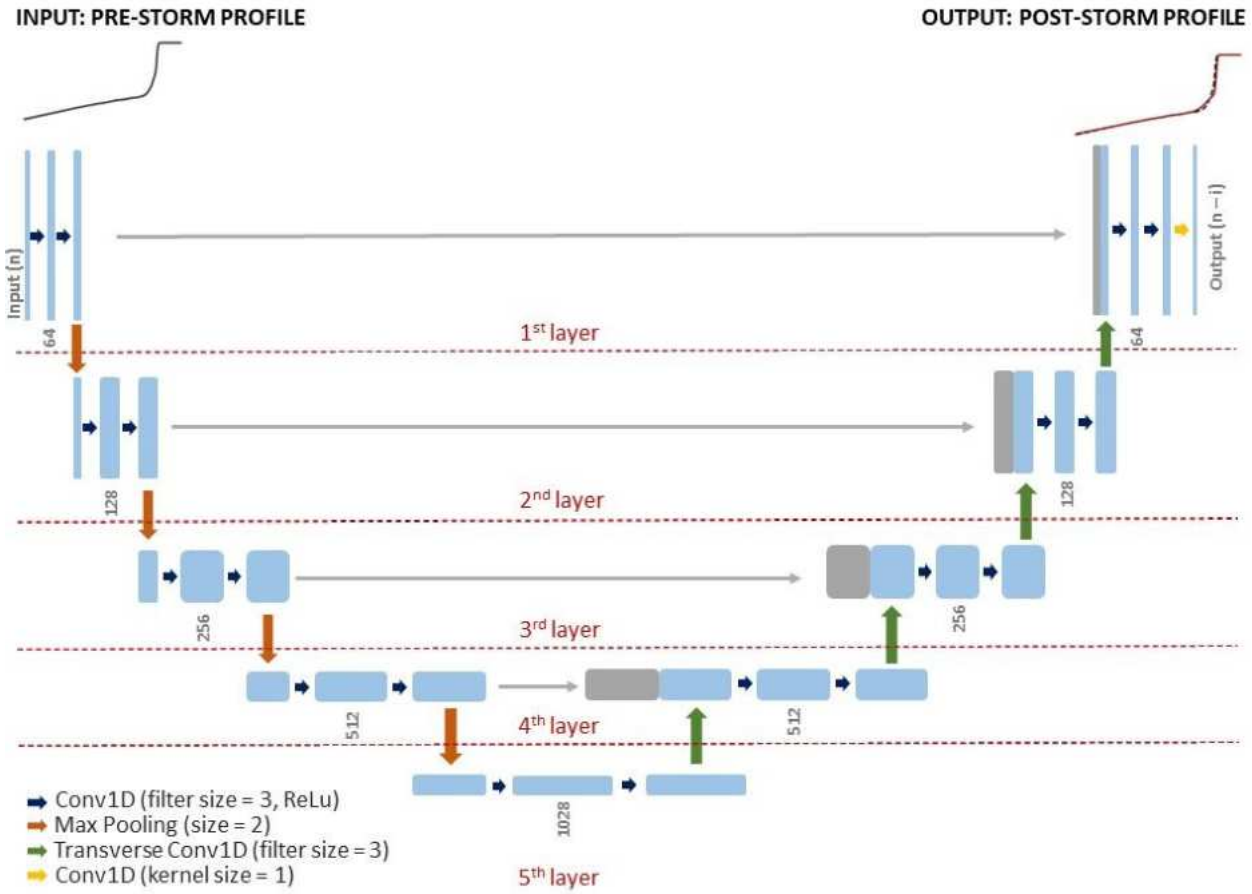
Exploration: Pre-Processing

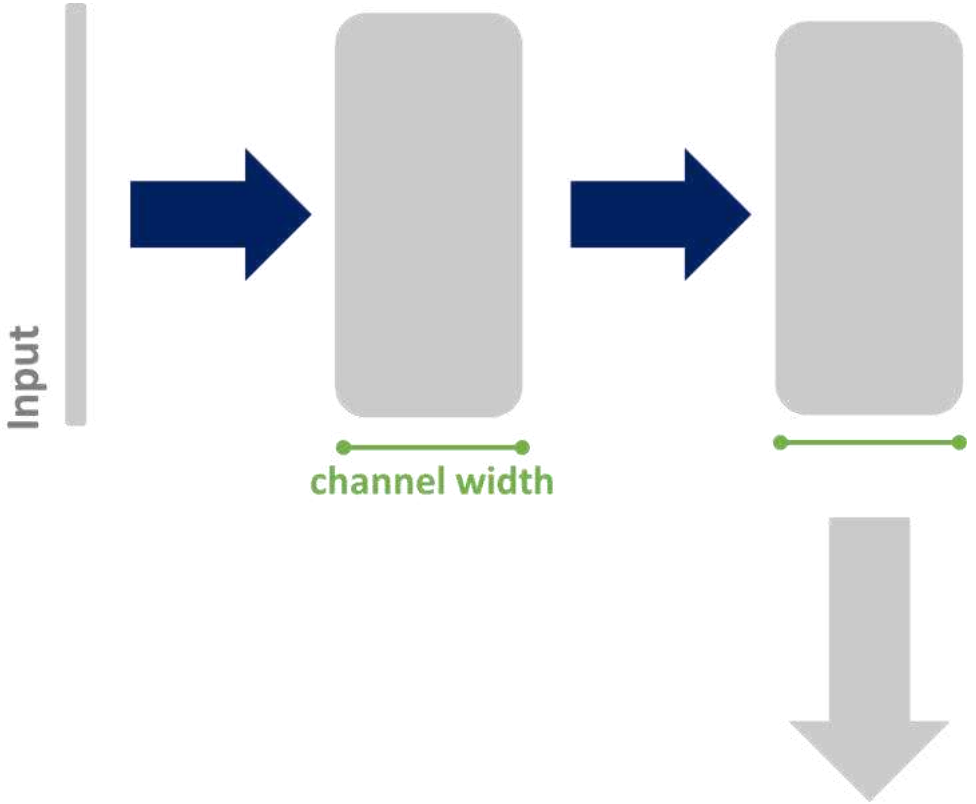




Methods

Exploration: Network structure

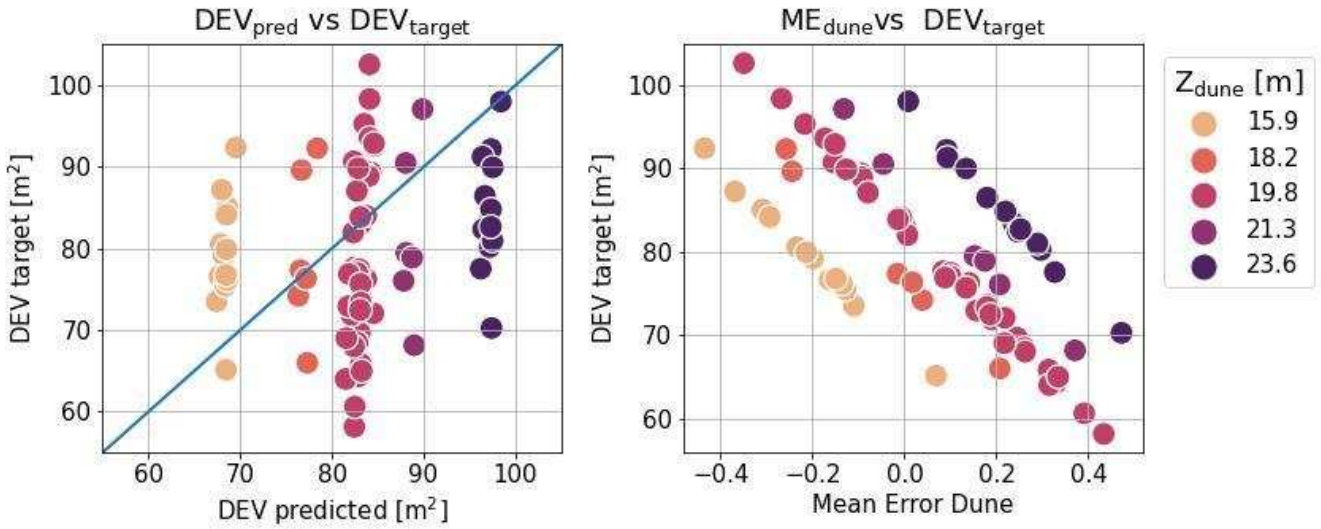




Results

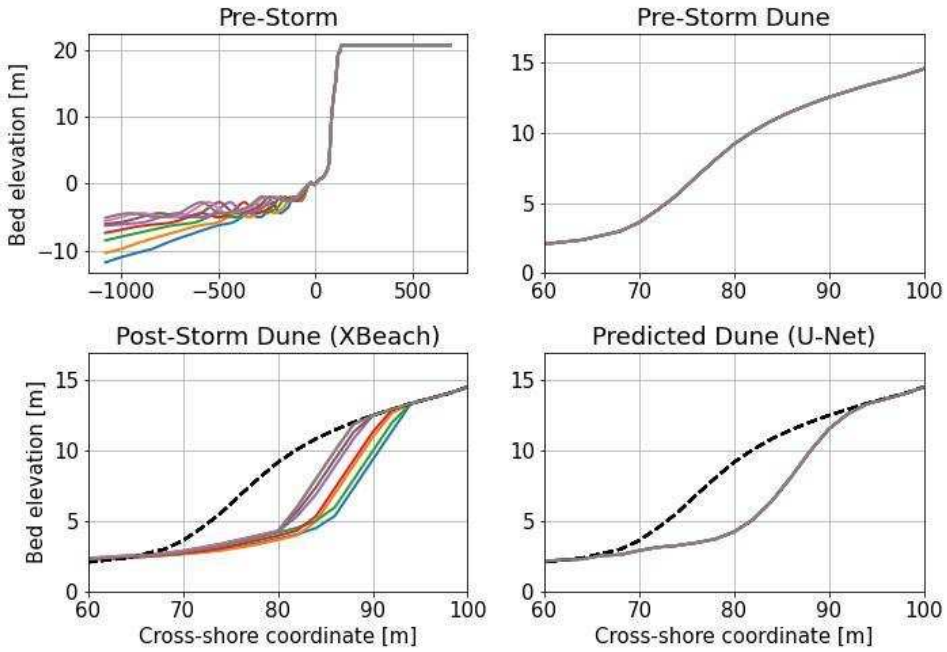
Exploration: Network structure

Test data



Relies on unsensitive parameter (dune height)

Training data

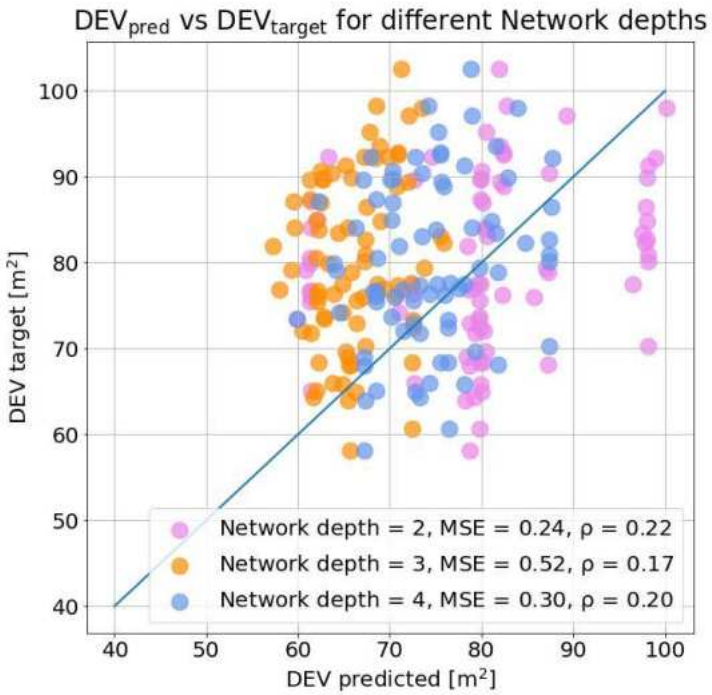


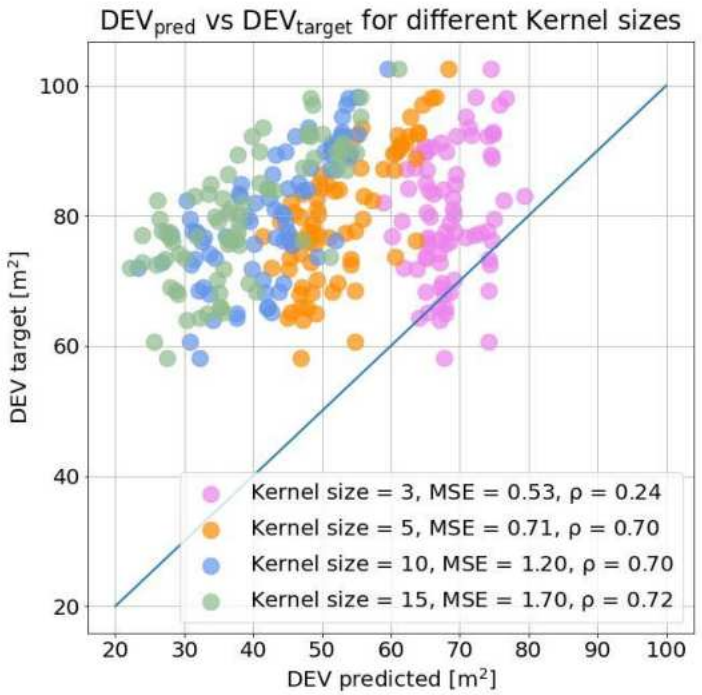
Does not rely on sensitive parameter (nearshore slope)

Results

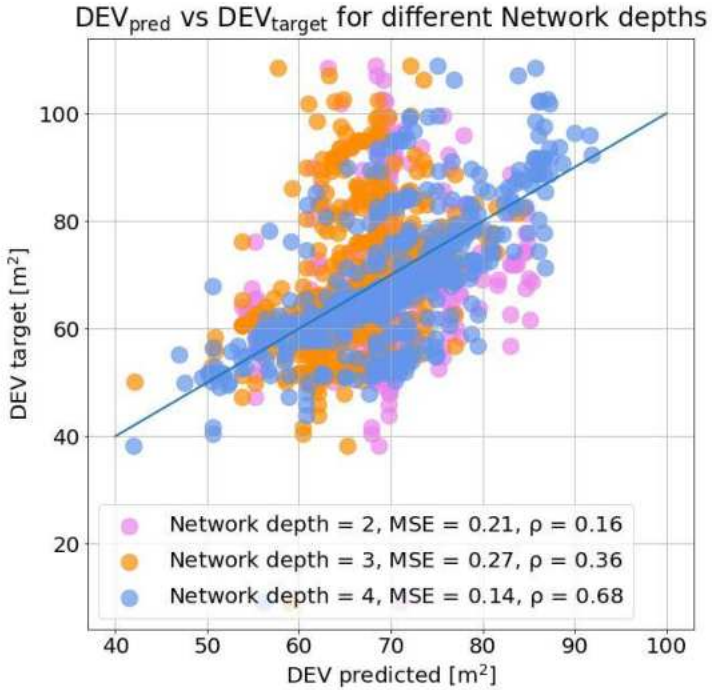
Exploration: Network structure

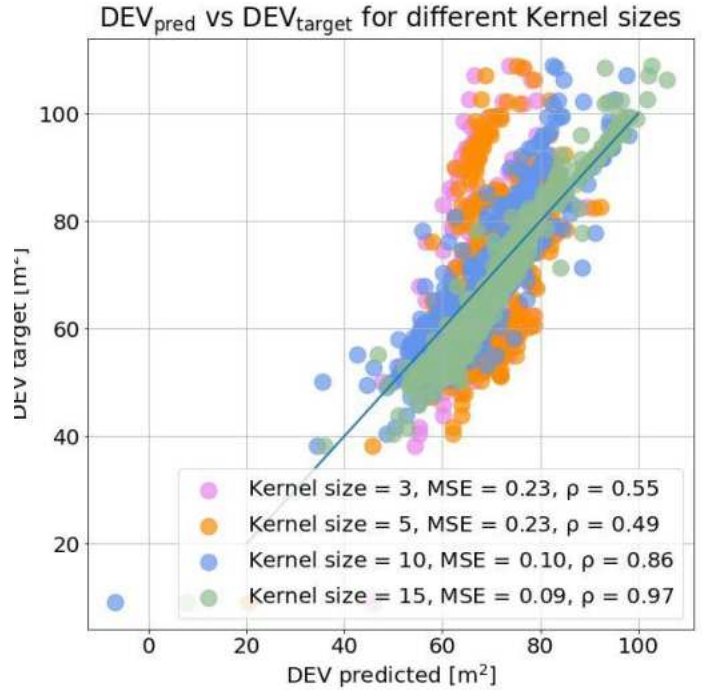
Test data





Training data

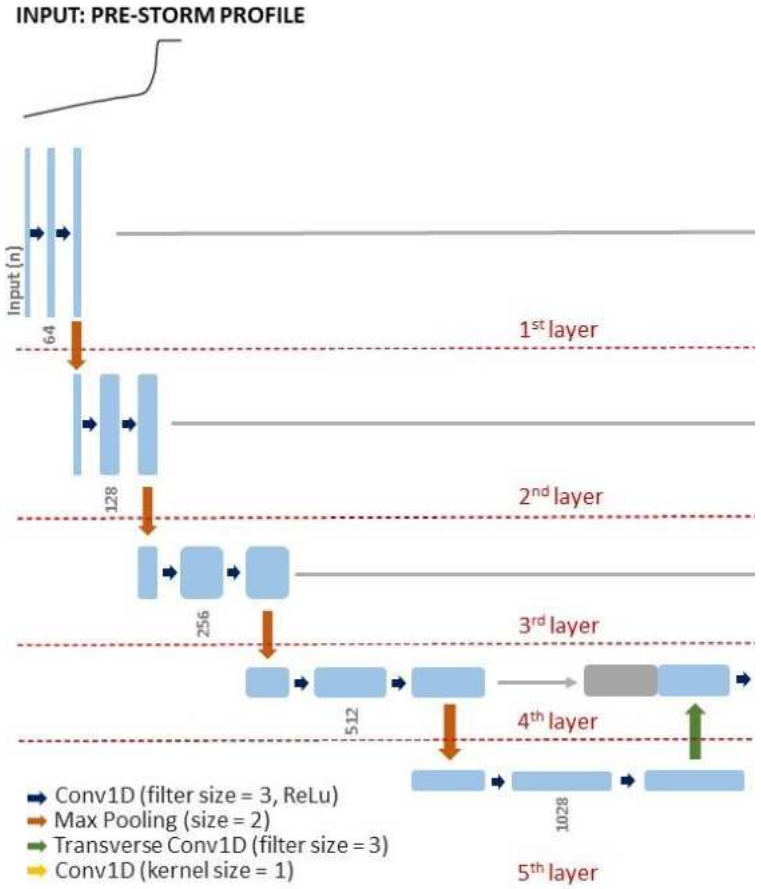




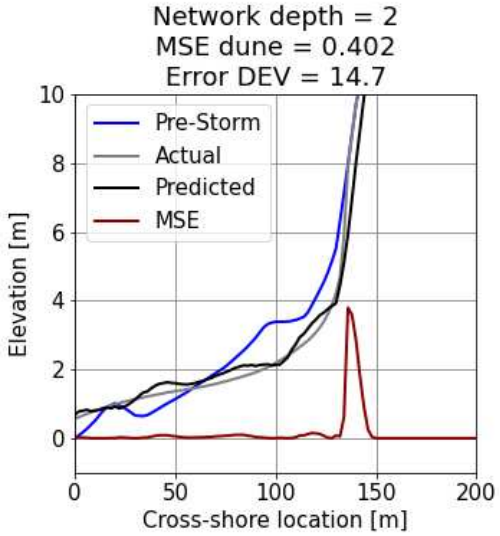
Deltares

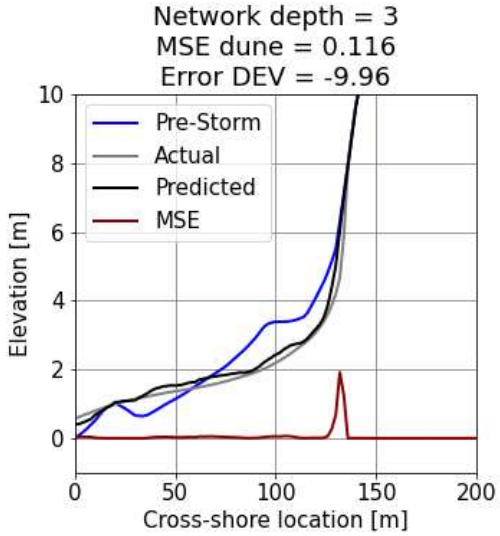
Results

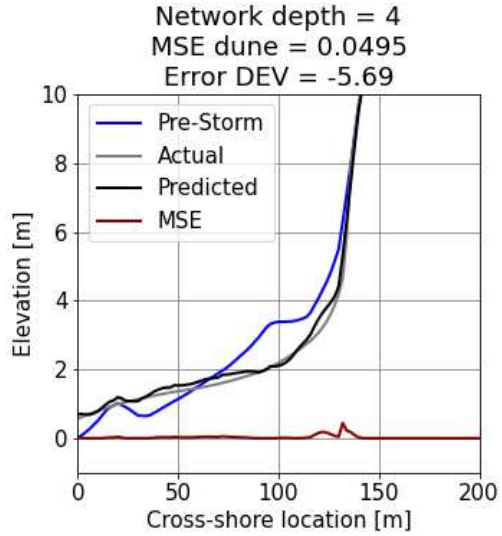
Network Depth



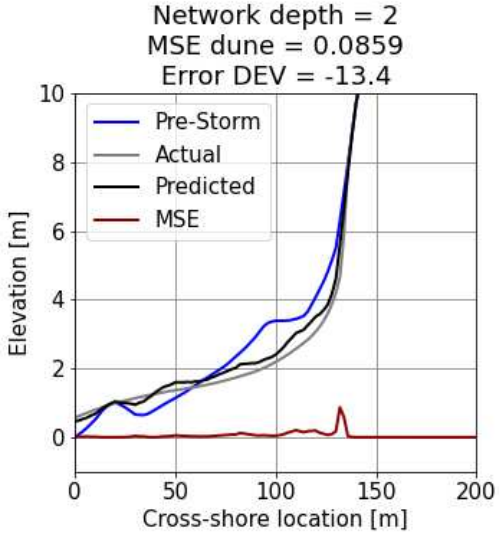
Profile for for different network depths, kernel size = 3

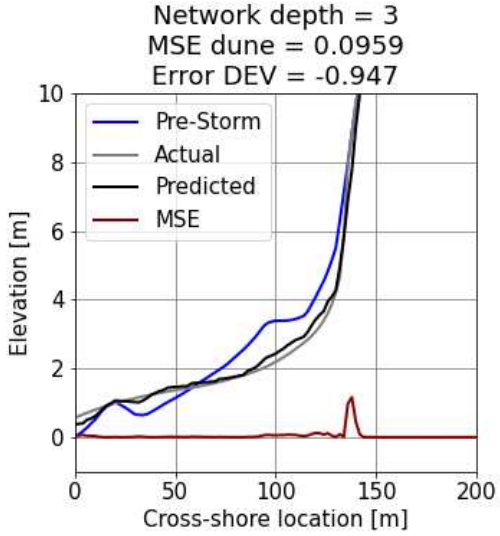


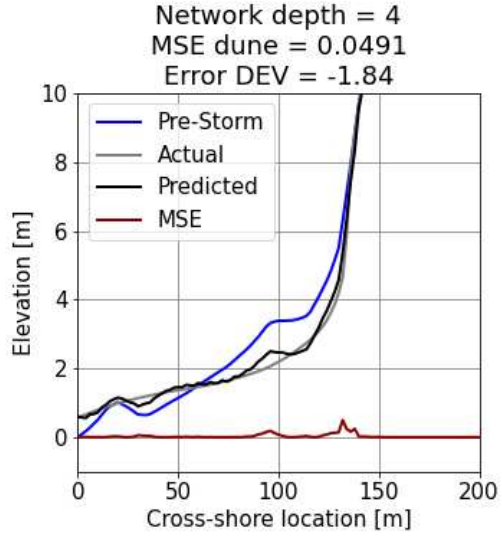




Profile for for different network depths, kernel size = 10

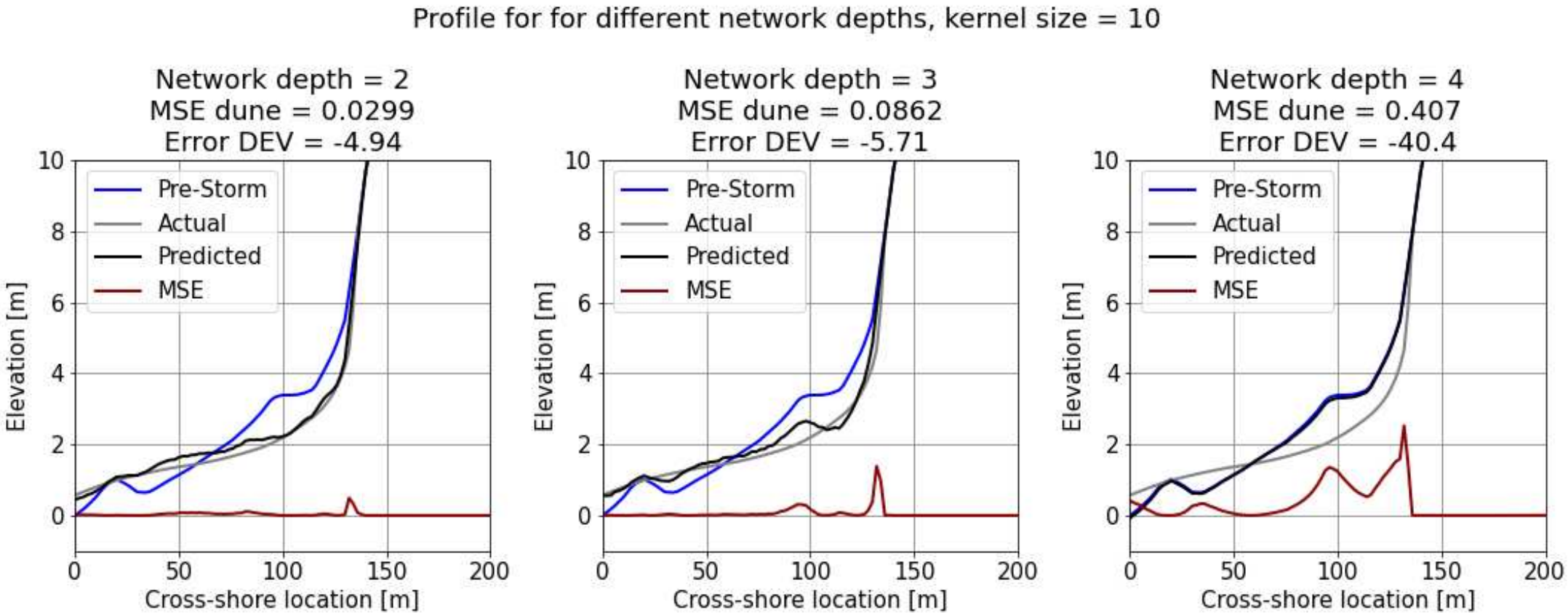






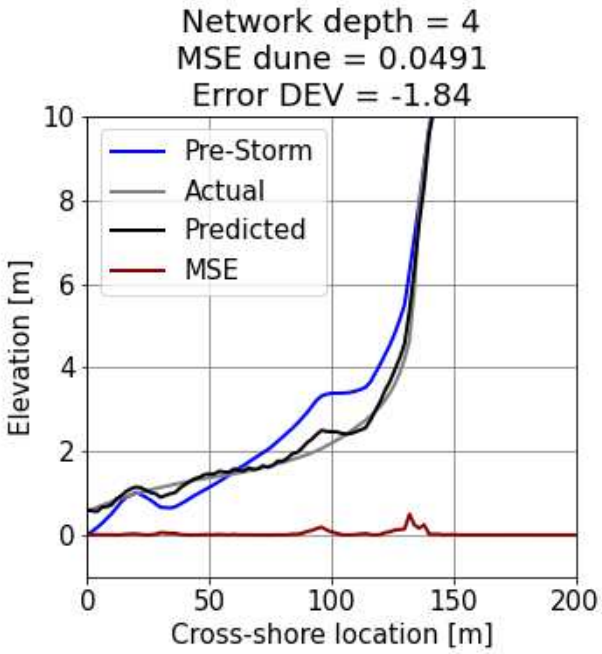
Deltares

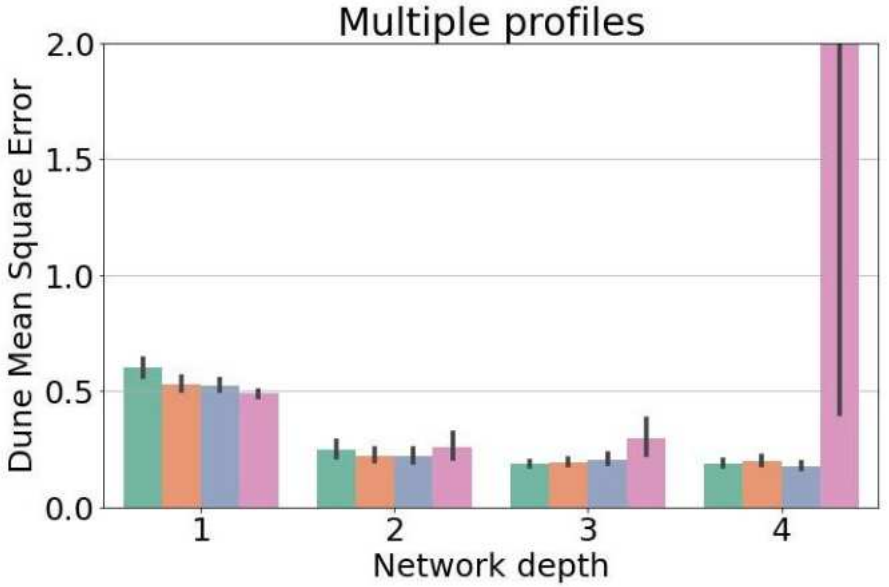
Loss predictive capability ND4, kernel size 10

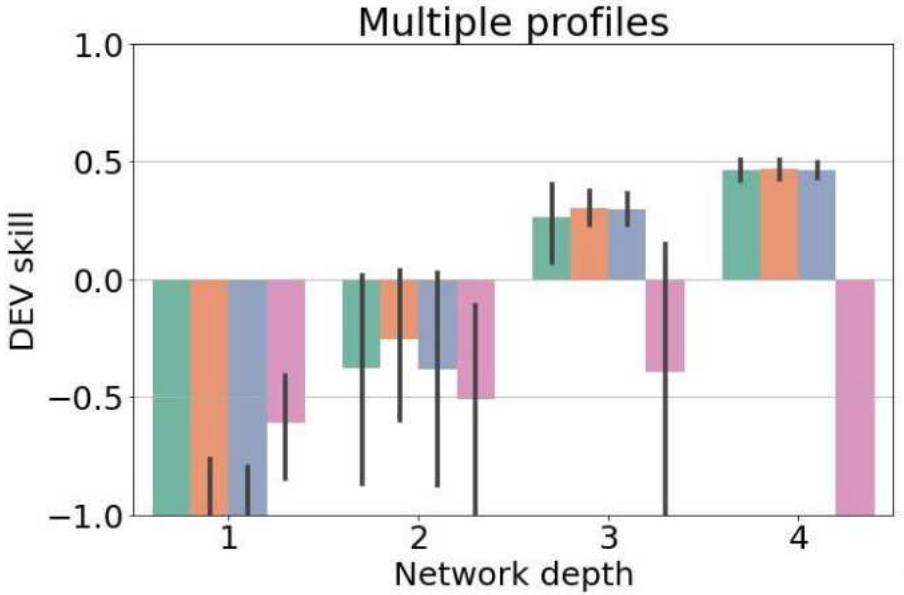


Discussion

- Performance metric







Conclusion

Driving mechanisms of dune erosion

- What **morphological response** is found in post-storm dune profile shapes, using a dataset of simplified pre-storm sandy profile shapes and XBeach?

Surrogate modelling

- What **performance metrics** can be used to evaluate surrogate models for post-storm profile shape prediction?
- To what extent are **pre-processing tools and neural networks** able to make post-storm profile shape predictions for a simplified dataset?

Upscaling

- Can neural networks be used for predicting post-storm profiles of **actual** Holland coast profile shapes?

Conclusion

Driving mechanisms of dune erosion

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- Can neural networks be used for predicting post-storm profiles of **actual** Holland coast profile shapes?

U-Flood

- Storm conditions