Automatic detection of waterbeds in shallow and muddy water bodies in the Netherlands using green LiDAR

Vasileios Alexandridis 2020

TU Delft

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Delegate: Angeliki Sioli

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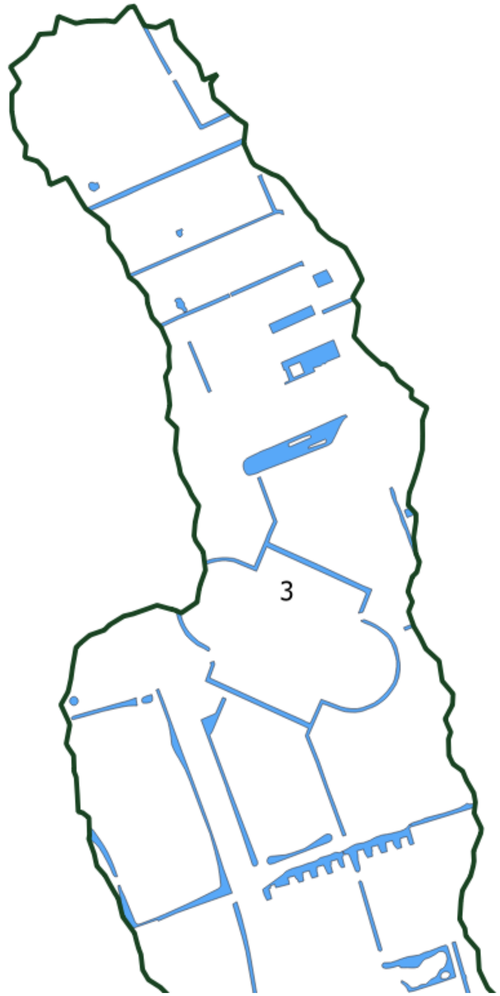
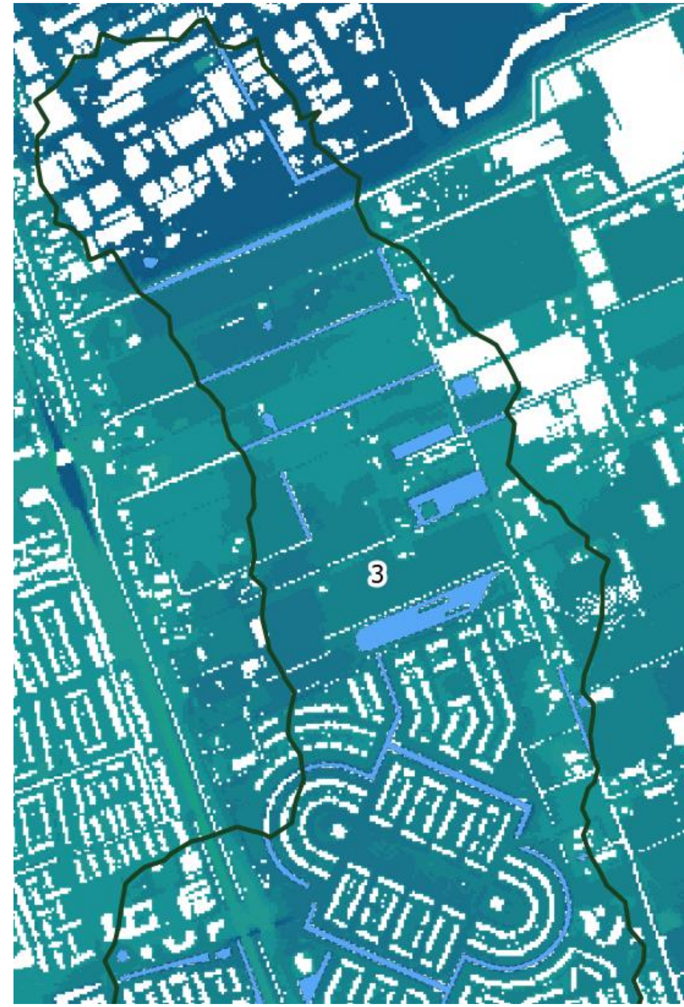
Introduction





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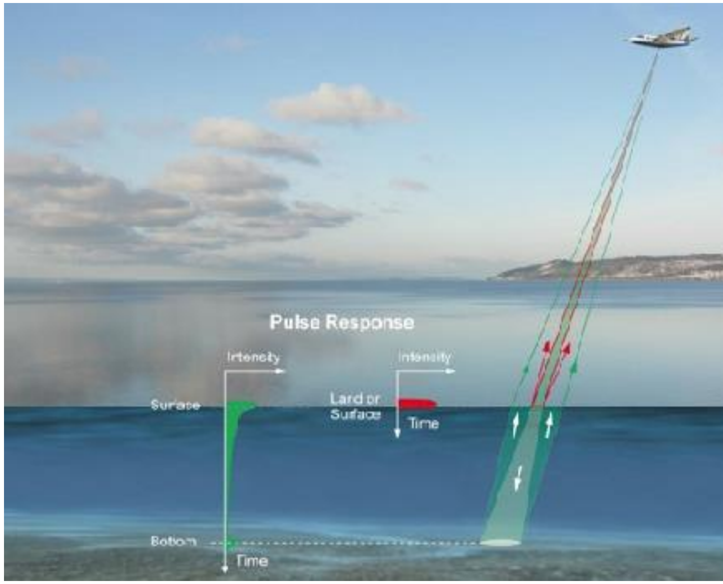
Introduction



Airborne LiDAR bathymetry (ALB)

Source : “Pilotproject: Meten ondiepe sloten in de polder groot wilnis vinkeveen met laser bathymetry“
[Aerodata, 2015]

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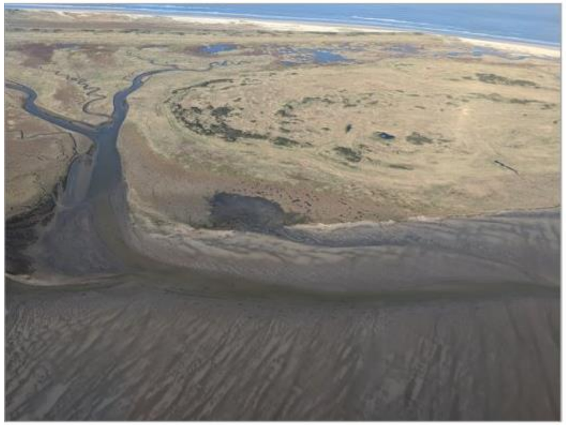
Motivation

- ❖ Previous studies tried to detect waterbeds in water bodies using bathymetric LIDAR data in case of the Netherlands
- ❖ However, developed methods have **not** succeeded in detecting **bottom points** with high certainty and accuracy.
- ❖ Other methods (e.g. pulse, neighbourhood-based) could improve the detection process and deal particularly with shallow and muddy water bodies.



Source: Shallow and muddy water areas, Wadden Sea 2019 (Deltares)

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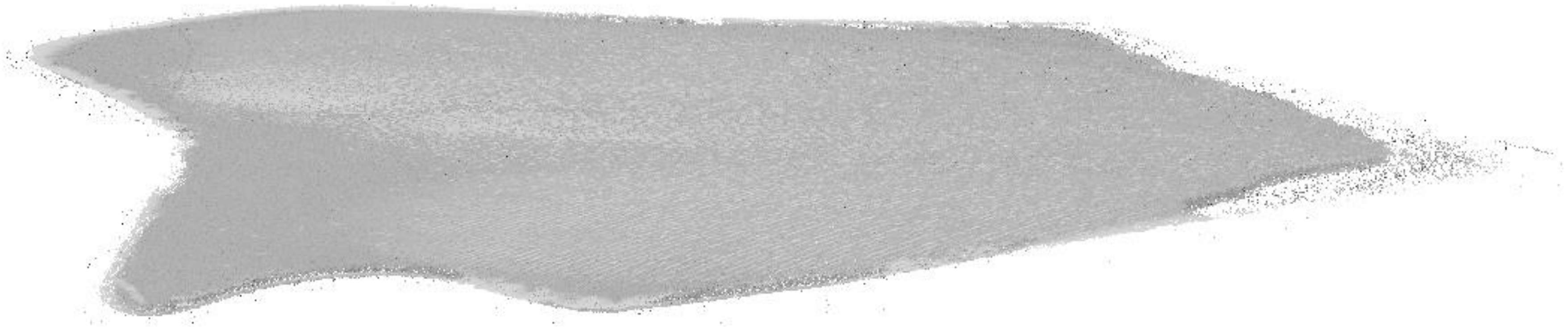
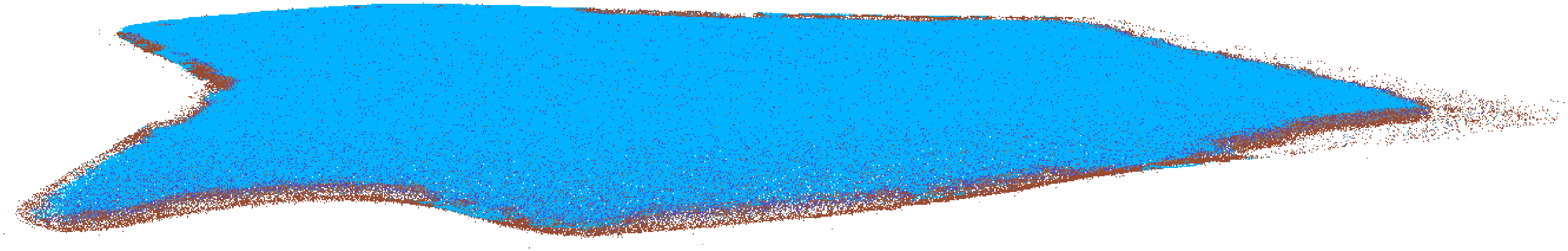
Main goal of study

From: an unclassified green airborne LiDAR



To: a classified green airborne LiDAR



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Related work

- Several studies have been done in the field of mapping river and shallow water body using green LiDAR.

Using only green LiDAR

- ✓ Green (532 nm)

(Mandburger et.al., 2015)

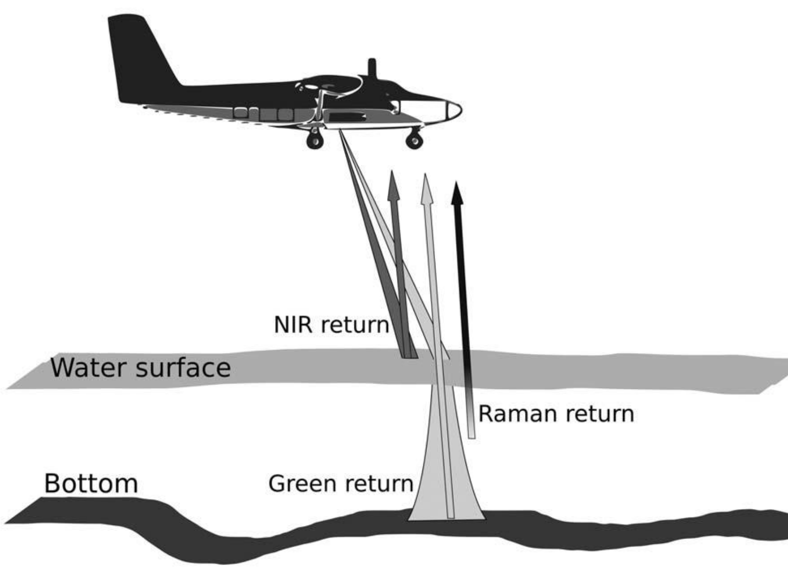
Using green LiDAR + additional data

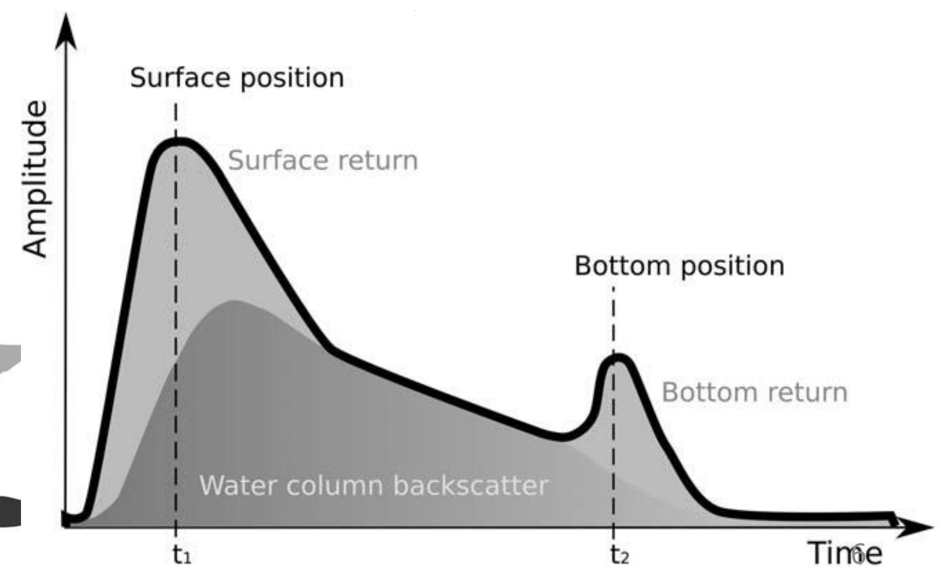
- ✓ NIR (1064 nm)
- ✓ Raman (647 nm)

(Allouis et.al., 2010)

- ✓ IR (700 nm – 1mm)

(Zhao et.al., 2017)





Related work

- ❖ Dutch waterboards collected ALB dataset using NIR and green LiDAR (Aerodata., 2015)

  Water depth measurements were collected

- ❖ Laboratory study tested the use of yellow wavelength (590nm) (Vazquez., 2017a)

Source : [Vazquez, 2017a]

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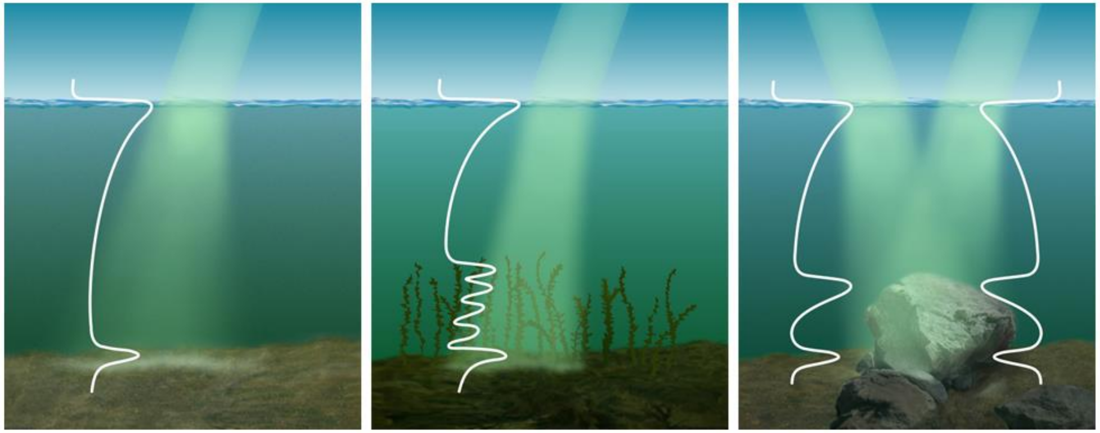
Related work

❖ Many environmental factors can negatively influence the direction, strength and shape of the laser pulse.

- ✓ Water clarity
- ✓ Organic particles & Suspended sediments
- ✓ Water turbidity (waves)
- ✓ Vegetation



Waterbed Vegetation Objects (e.g. rocks)

Direction of waveform into the water (Deltares)

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Related work

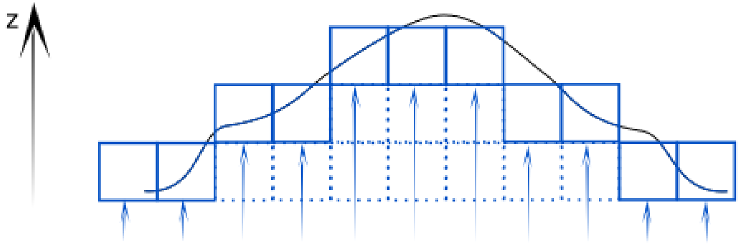
❖ **Pulse** and **Neighbourhood** – based methods:

✓ Points' characteristics

(Meng et. al., 2010)

✓ Local neighbourhood of points (Boerner et. al., 2017)

✓ Voxelization for ground segmentation



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Research Questions

Q1: Can the bottom points of shallow and muddy water bodies in the Netherlands be automatically detected using ALB?

q2: Can pulse and/or neighbourhood - based methods in a green ALB be used to classify and detect the bottom points?

q3: What is the influence of different voxel resolutions for classification, in terms of accuracy and computation load?

q4: How does the various point cloud quality (i.e. density, outliers) affect the classification process?

q5: Can a confidence value of water bodies be calculated? If it is possible, how?

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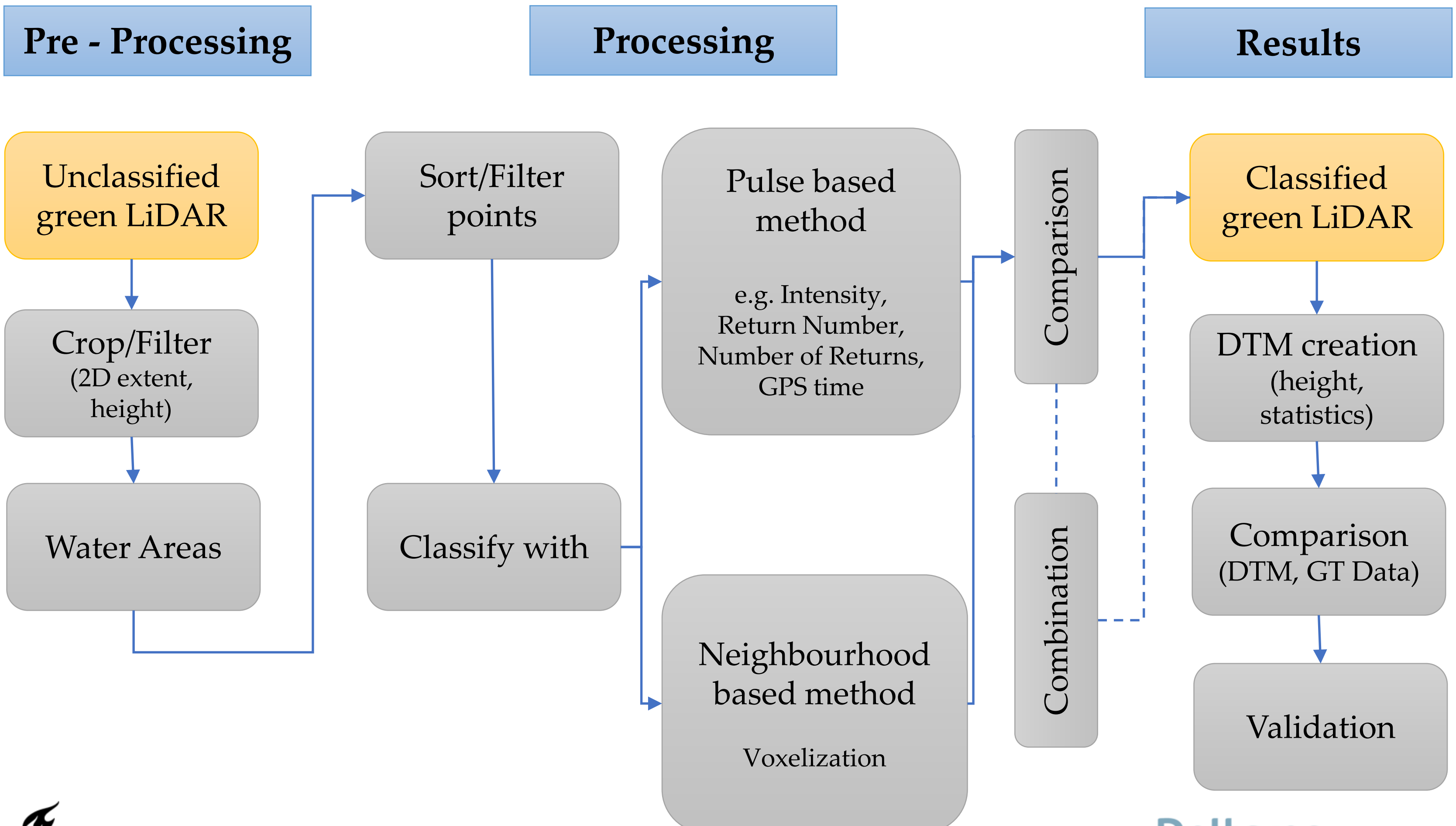
Methodology

Flowchart



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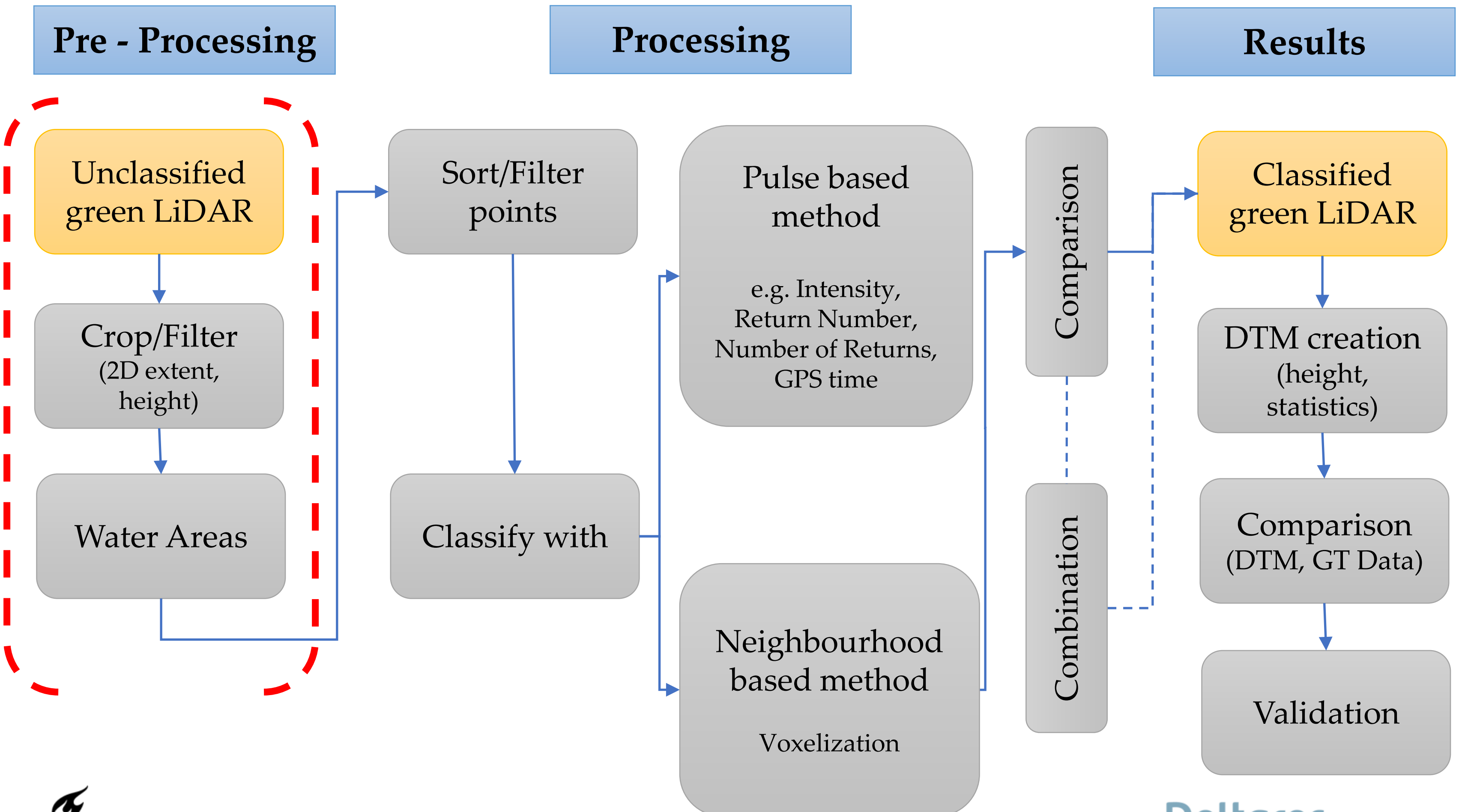
Methodology

Steps



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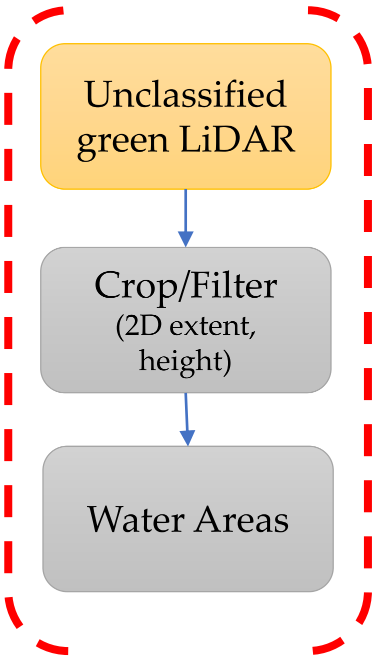
Methodology

Steps

Pre - Processing



Unclassified point cloud

- Green LiDAR data from 6 different regions
- For each region:

  - Crop water bodies using *TOP10NL* water polygons

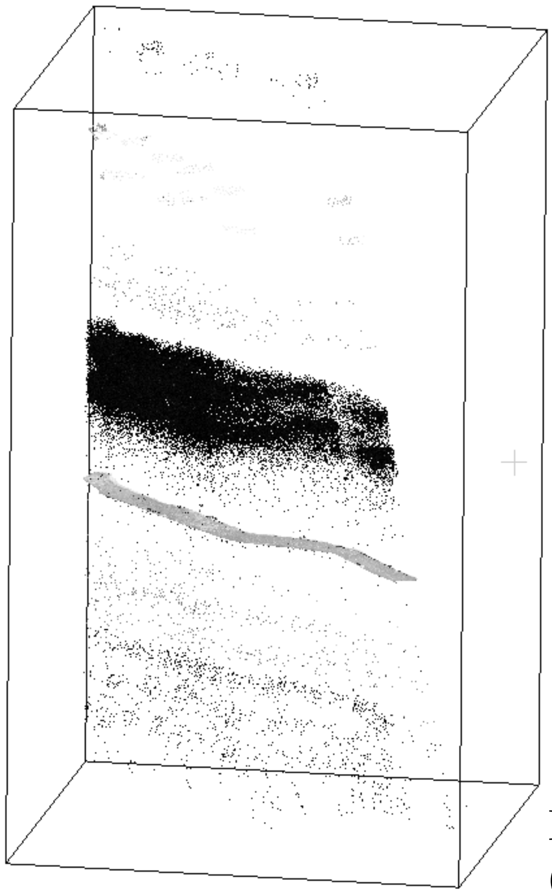
  - Filter them in z dimension (height thresholds)

  - Store them into separate LAZ files (LAStools)

  - Process only 5 water bodies from 6 regions

Methodology

Pre-processing



Presence of outliers
(*low/high z level)

3D view of a water body

1,2 million points
-2m to 0m

Cropped in z
extent

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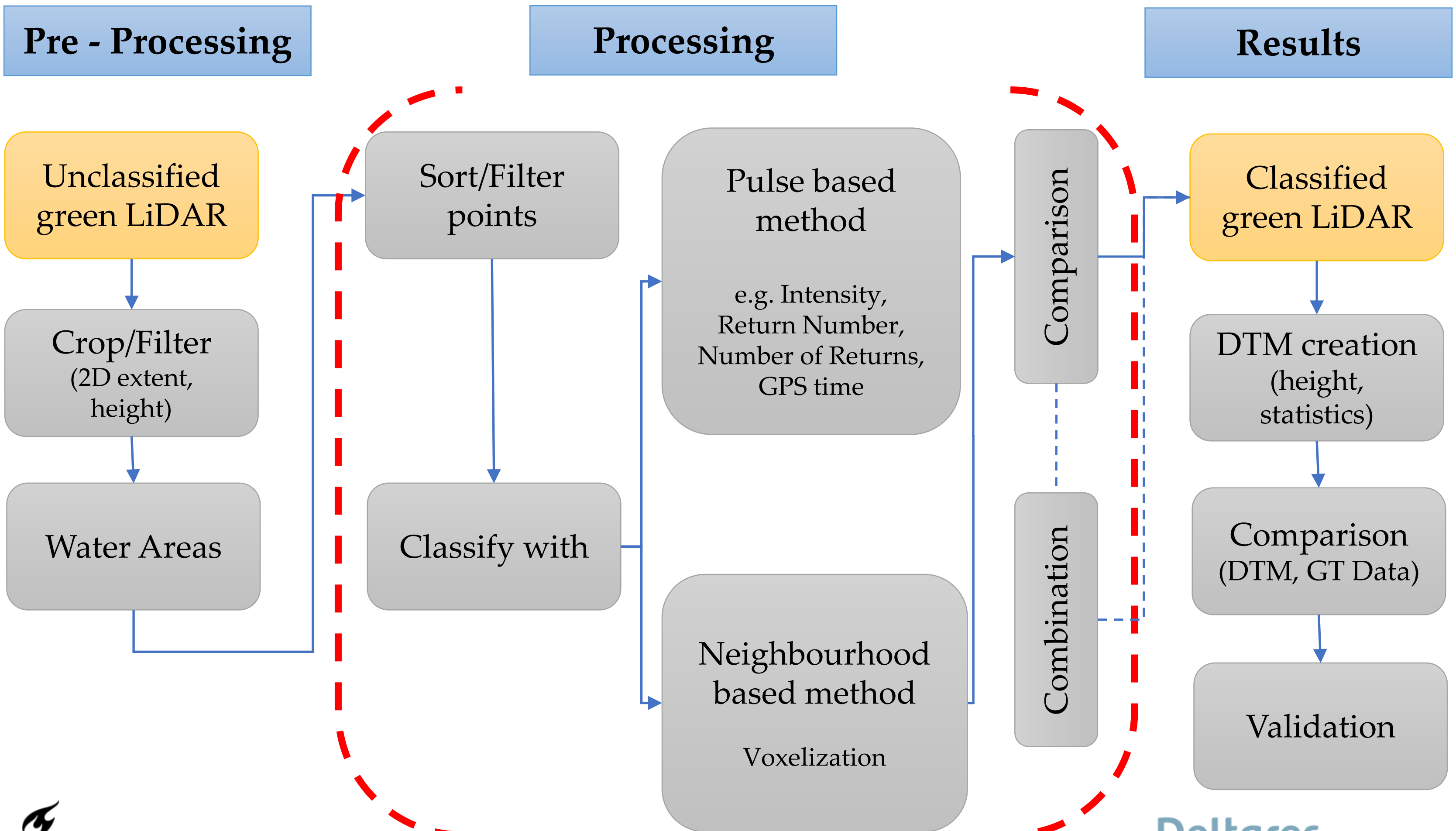
Methodology

Steps



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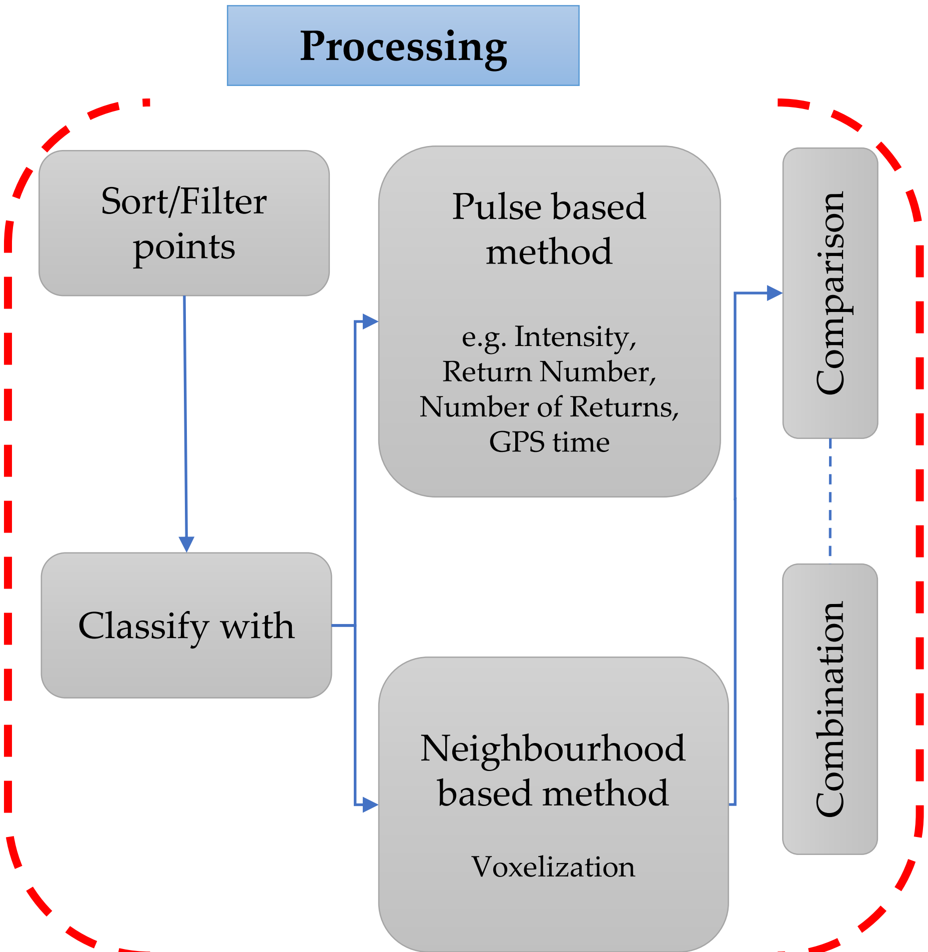
Methodology

Steps



- Sort per GPS time

To assure data contains right info

- Quality check of Discrete LiDAR (LAStools)
  - Completeness (all returns in the file)
  - Correctness (correct return numbers)

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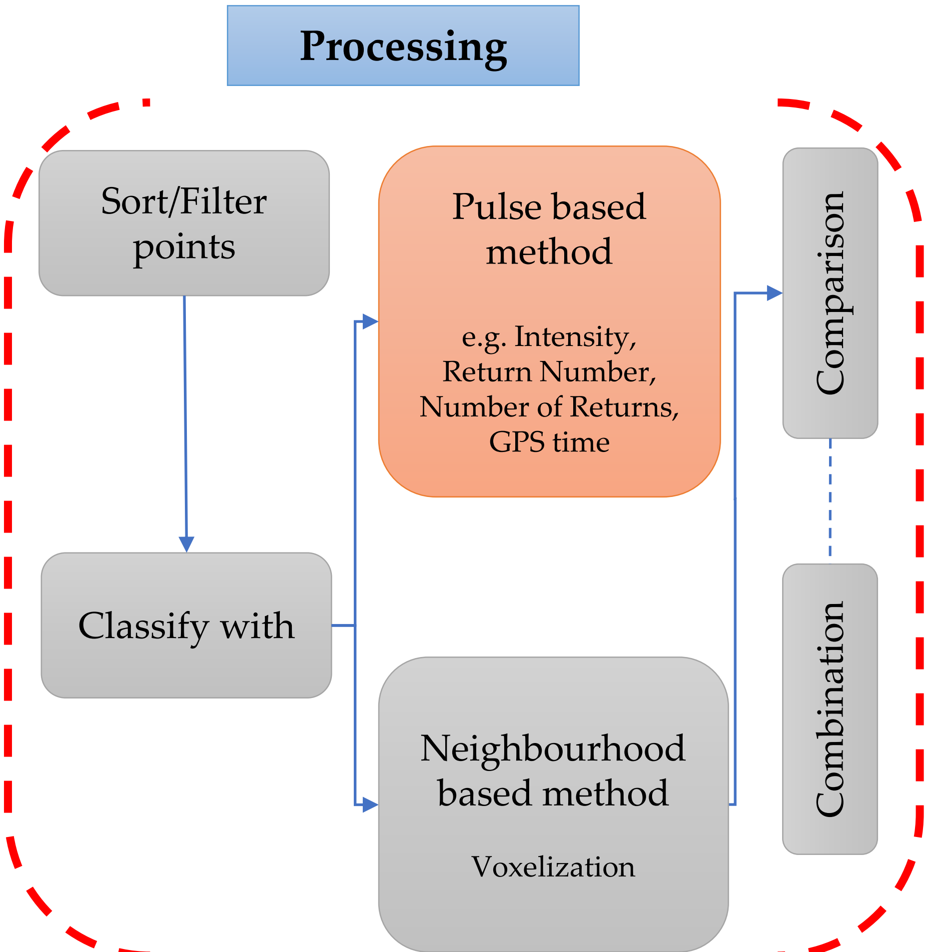
Methodology

Steps



- Pulse approximation
  - recontruct waveform with discrete returns
- Group points per pulse
  - use points' characteristics

  1. return number (rn)
  2. number of returns (nr)
  3. GPS time
  4. intensity
- Classes: water-surface (1st point)
  water/bottom (2nd/2nd point)
  bottom (3rd point)

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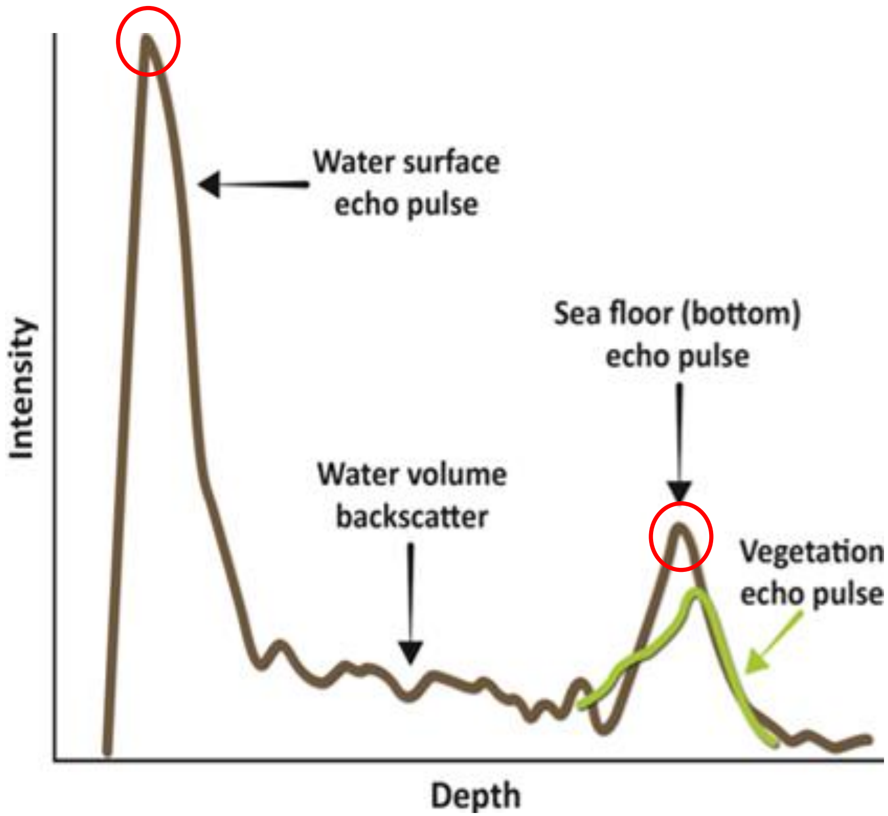
Pulse – based method

Theory – How?



Source: [Iqmulus,2019]

- Laser pulse
  - Depth (↑)
  - Intensity (↓)
- Small peak (intensity)
- Potential bottom point

Pulse: >2 returns → $\frac{Intensity\ (last\ return)}{Intensity\ (previous\ return)} > 1$

Pulse: 2 returns → Last return

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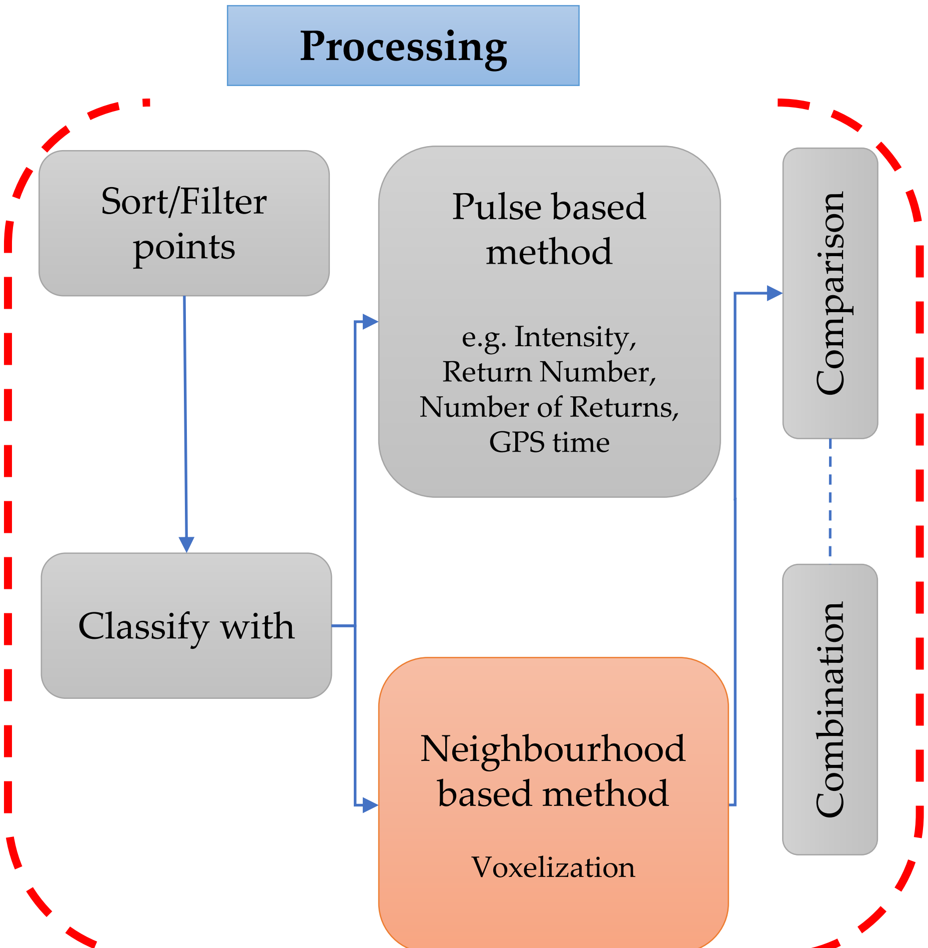
Methodology

Steps



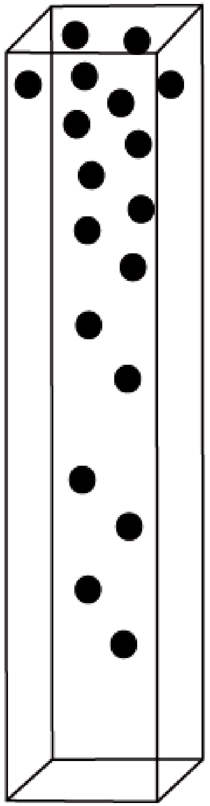
- 3D Voxel structure
- Voxel size selection:
  - Density
  - Area
  - Processing time
- Points per Voxel/Water column

Histogram

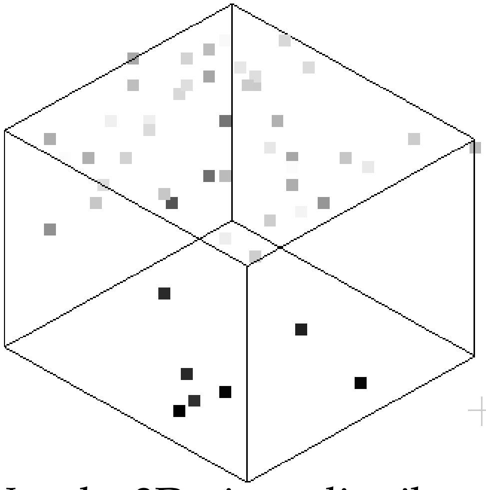
Detect peaks (1^{nd} & 2^{nd}) → Confidence values

Voxel – based method

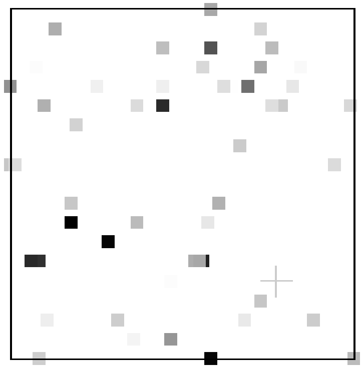
Theory - 3D Voxel structure



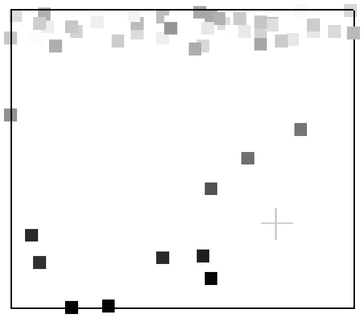
3D Voxel - Water column



Voxel – 3D view; distributed points



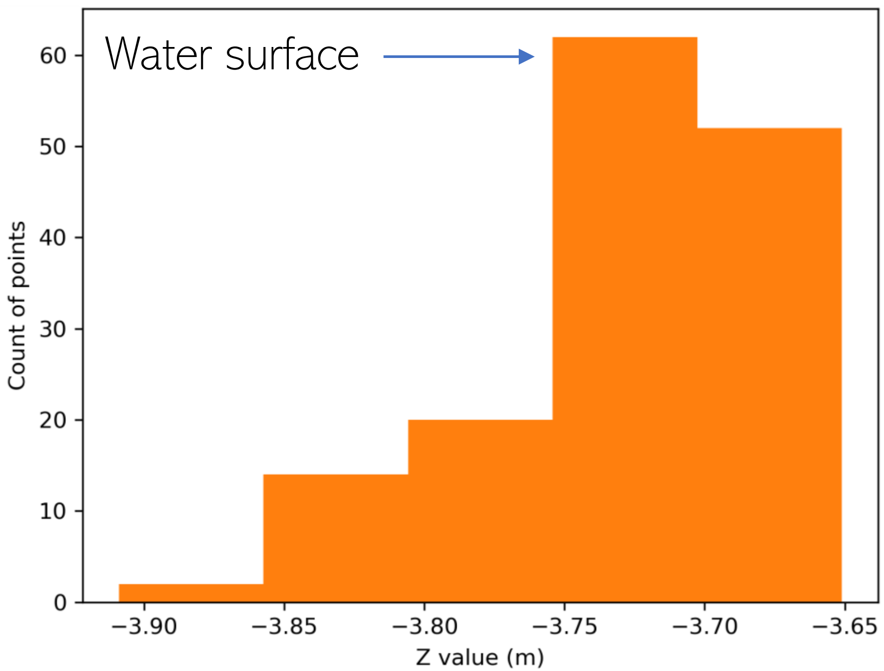
Top view



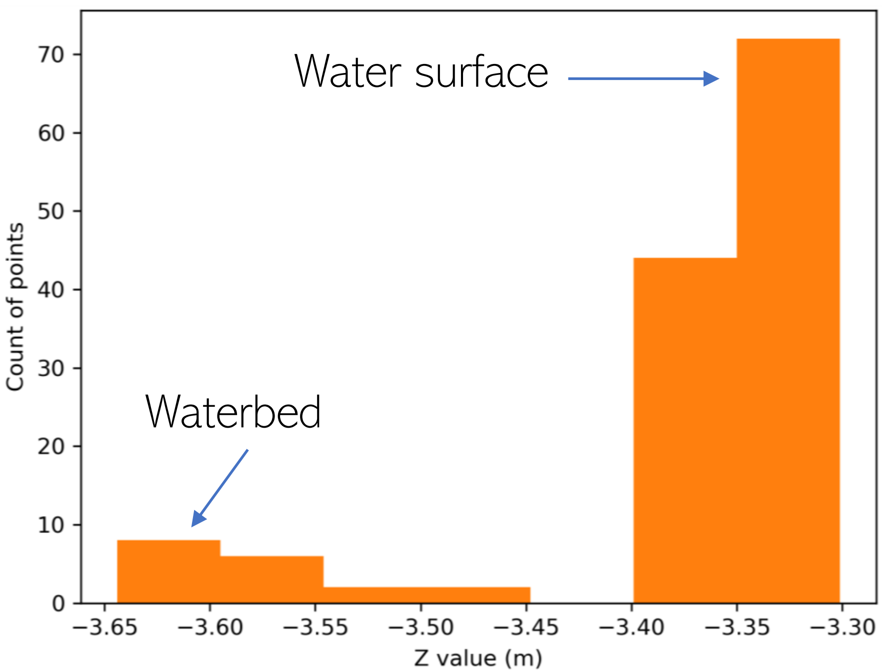
Section view

Voxel – based method

Theory – Histogram and Peaks' Detection



Example 1: Voxel with **one** peak

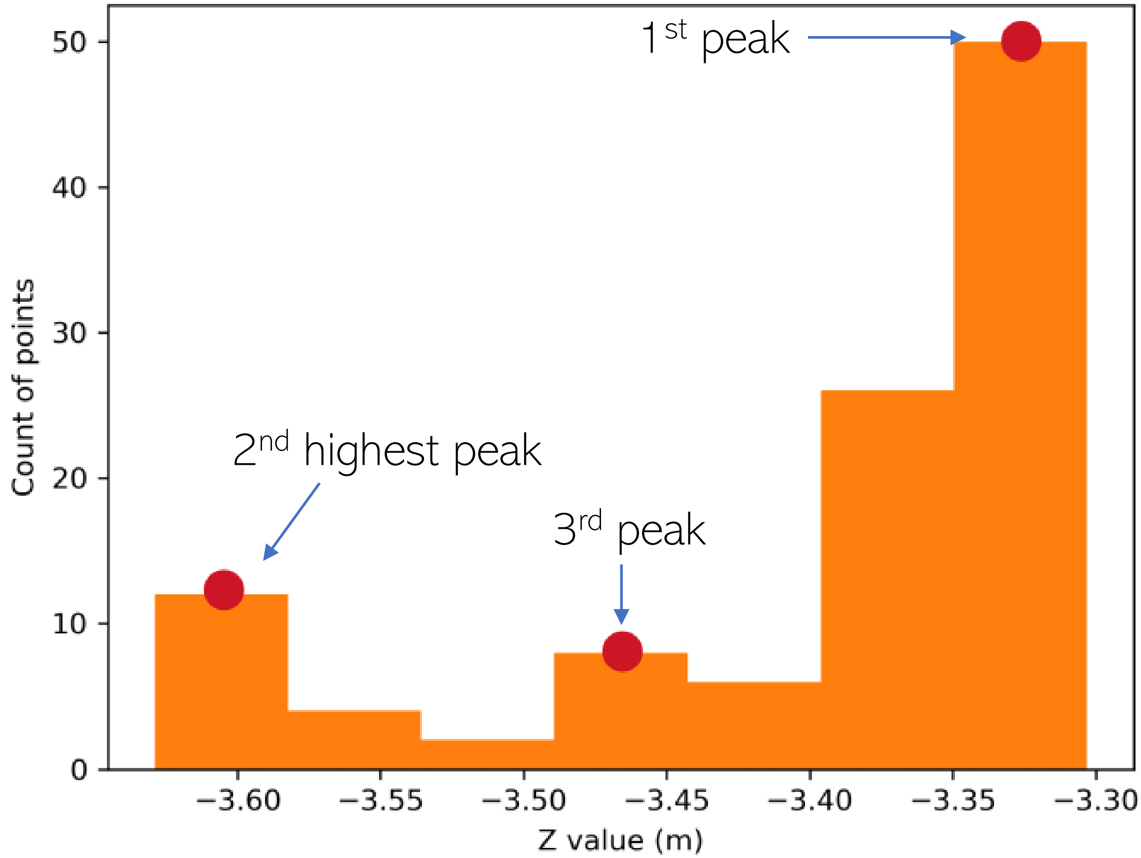


Example 2: Voxel with **two** peaks

Voxel – based method

Theory – Peaks' Detection

Case 1



- Histogram; constant bin size
- 3 peaks in histogram
- 1st peak: highest point of its bin

  → water surface

- 2nd peak: lowest point of its bin

  → potential bottom point *(how confident?)*

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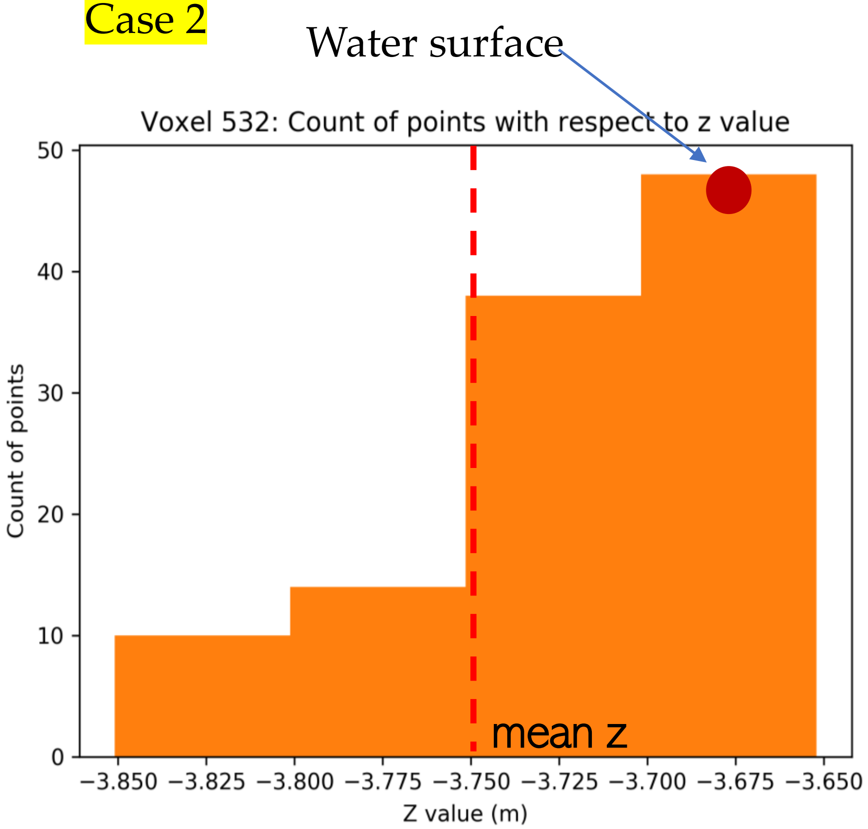
Voxel – based method

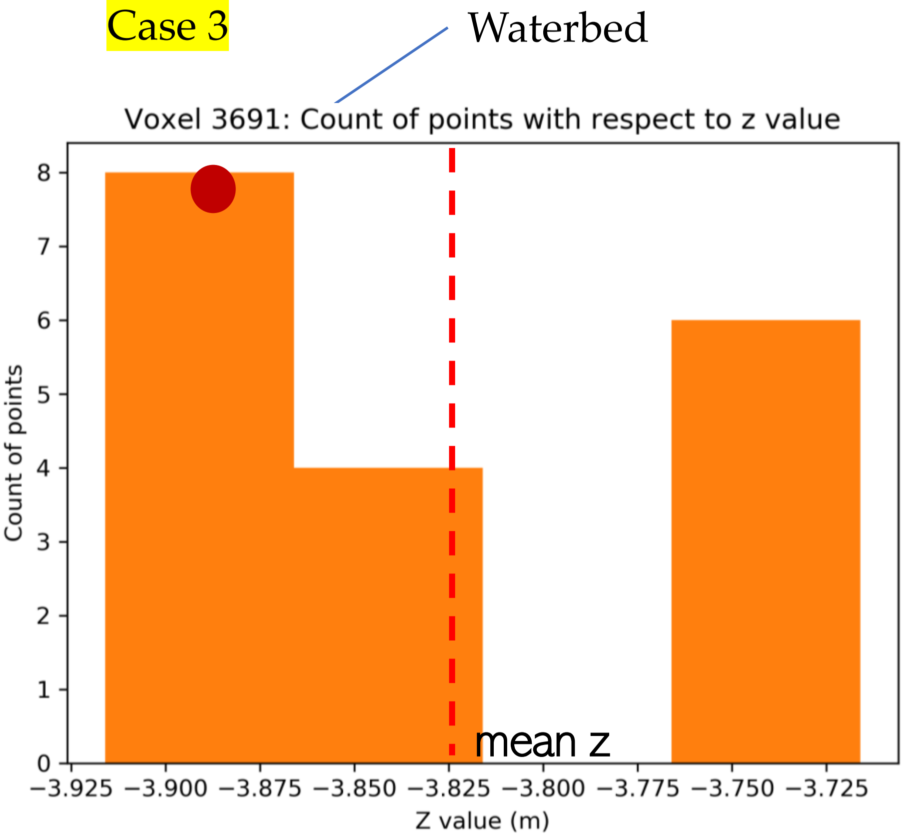
Theory – Peaks' Detection

Case 2



1 Peak > mean z

Case 3



1 Peak < mean z

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Voxel – based method

Theory – Confidence values

How certain is a point to be **bottom**? → Define condifence values based on:

Density (Number of points in bin)

Distance (Z level: 1st - 2nd peak)

Intensity (Lowest point)

Density (τ_{den})	*Distance* (τ_{dis})	*Intensity* (τ_{int})	*Conf. value*
$> \tau_{den}$	$> \tau_{dis}$	$> \tau_{inten}$	1
$> \tau_{den}$	$<= \tau_{dis}$	$> \tau_{inten}$	2
$> \tau_{den}$	$> \tau_{dis}$	$<= \tau_{inten}$	3
$<= \tau_{den}$	$> \tau_{dis}$	$> \tau_{inten}$	4
$<= \tau_{den}$	$> \tau_{dis}$	$<= \tau_{inten}$	5
$> \tau_{den}$	$<= \tau_{dis}$	$<= \tau_{inten}$	6
$<= \tau_{den}$	$<= \tau_{dis}$	$> \tau_{inten}$	7
$<= \tau_{den}$	$<= \tau_{dis}$	$<= \tau_{inten}$	8

- 8 values:
  - high confident: **(1)**
  - low confident: **(8)**
- 8 combinations based on **order**:
  1. Density/Intensity
  2. Distance
- (τ_{int}), (τ_{den}): **median**
- (τ_{dis}): ***mean***

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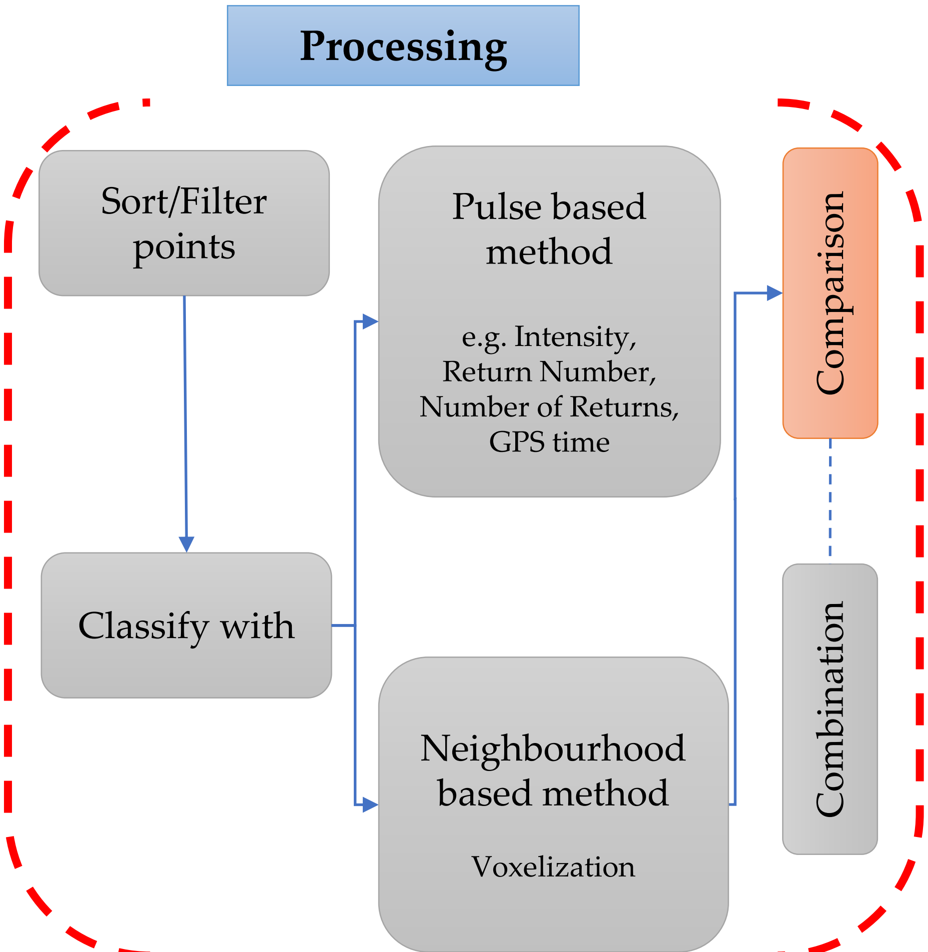
Methodology

Steps



Pulse – based method

- Points' attributes (NR, RN, GPS, Intensity)
- Easy-going process

Voxel – based method

- 2D regular grid
- Voxel size selection
- Spatial distribution of points
- Computationally demanding due to density of the data

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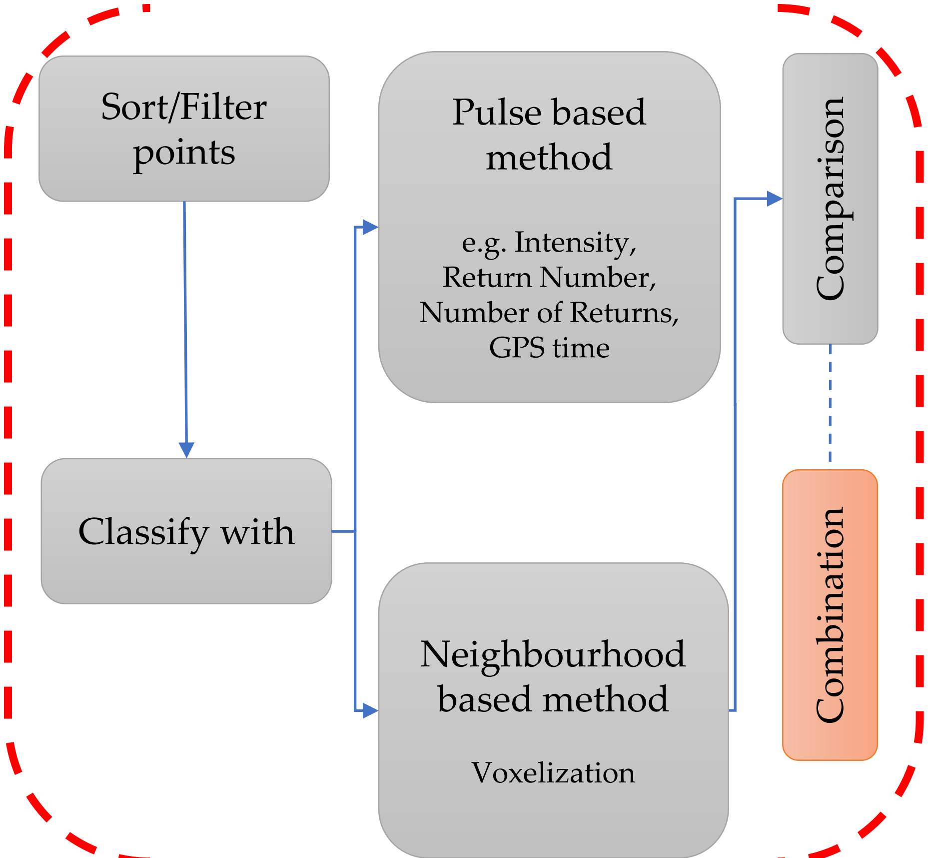
Methodology

Steps

Processing



Pulse & Voxel – based method

- Not all the points of a pulse always fall in a voxel due to the voxel size

↓

E.g. 3 returns in a pulse
Only the last return in the voxel

- Small voxel size to get more bottom points → then, combine with pulse bottom ones

↓

High computation time

Areas & Datasets

Green LiDAR data for 6 regions in the Netherlands
Acquired by: Riegl VQ-880-G laser scanner

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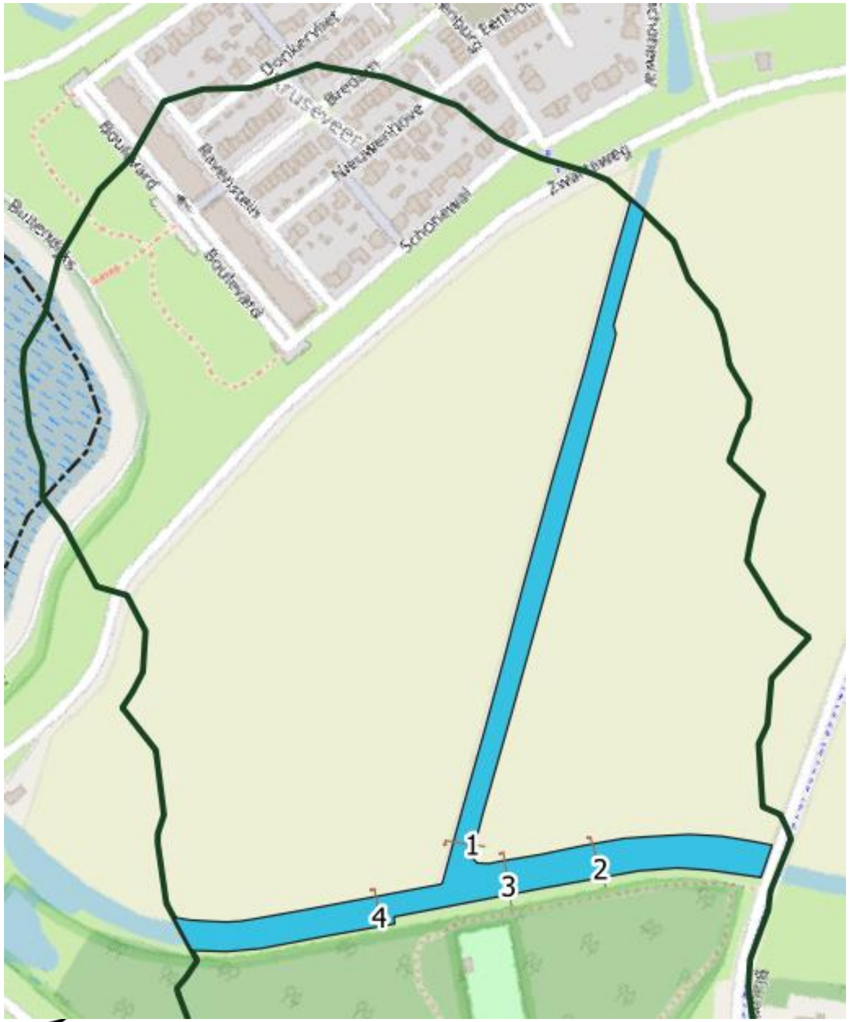
Areas & Datasets



Water body 51
Region NL1

Ground truth data

- GPS measurements of 4 profile sections
- Difficulties:
  - Presence of a sludge layer
  - Quality is affected by other factors:
    - ✓ water turbidity
    - ✓ vegetation (e.g. algae)
- Only for water body 51, Region NL1

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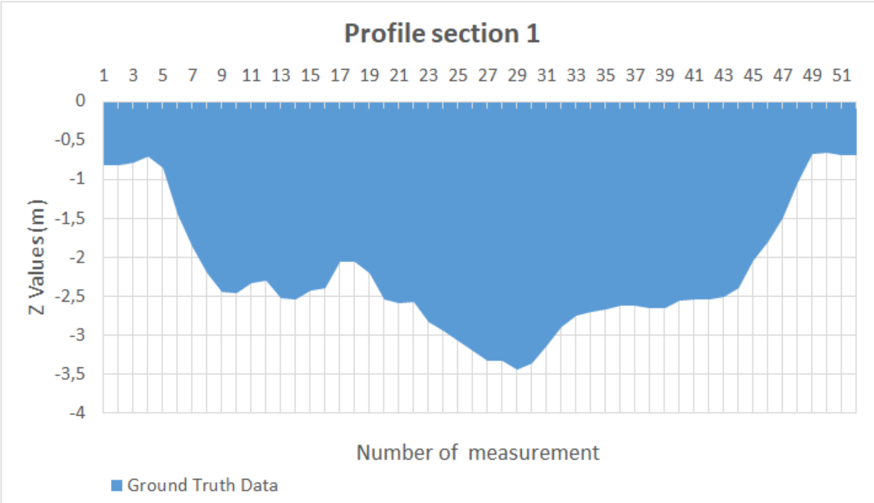
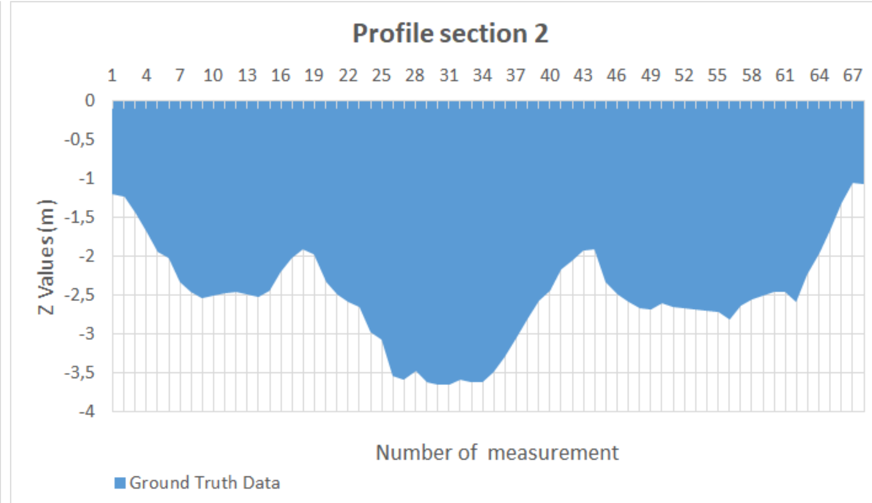
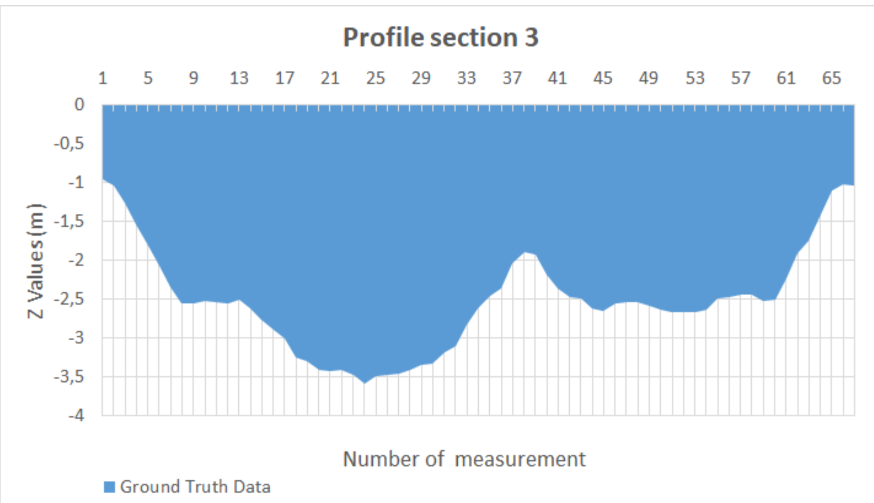
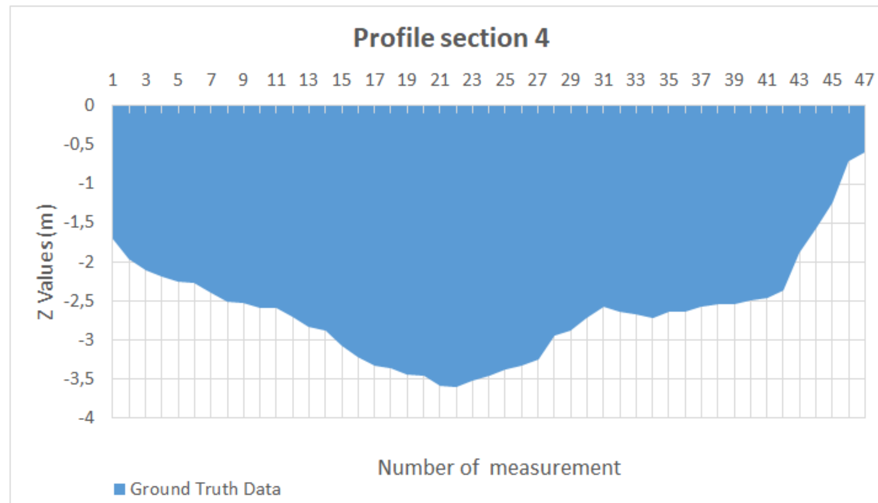
Areas & Datasets









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Ground truth data

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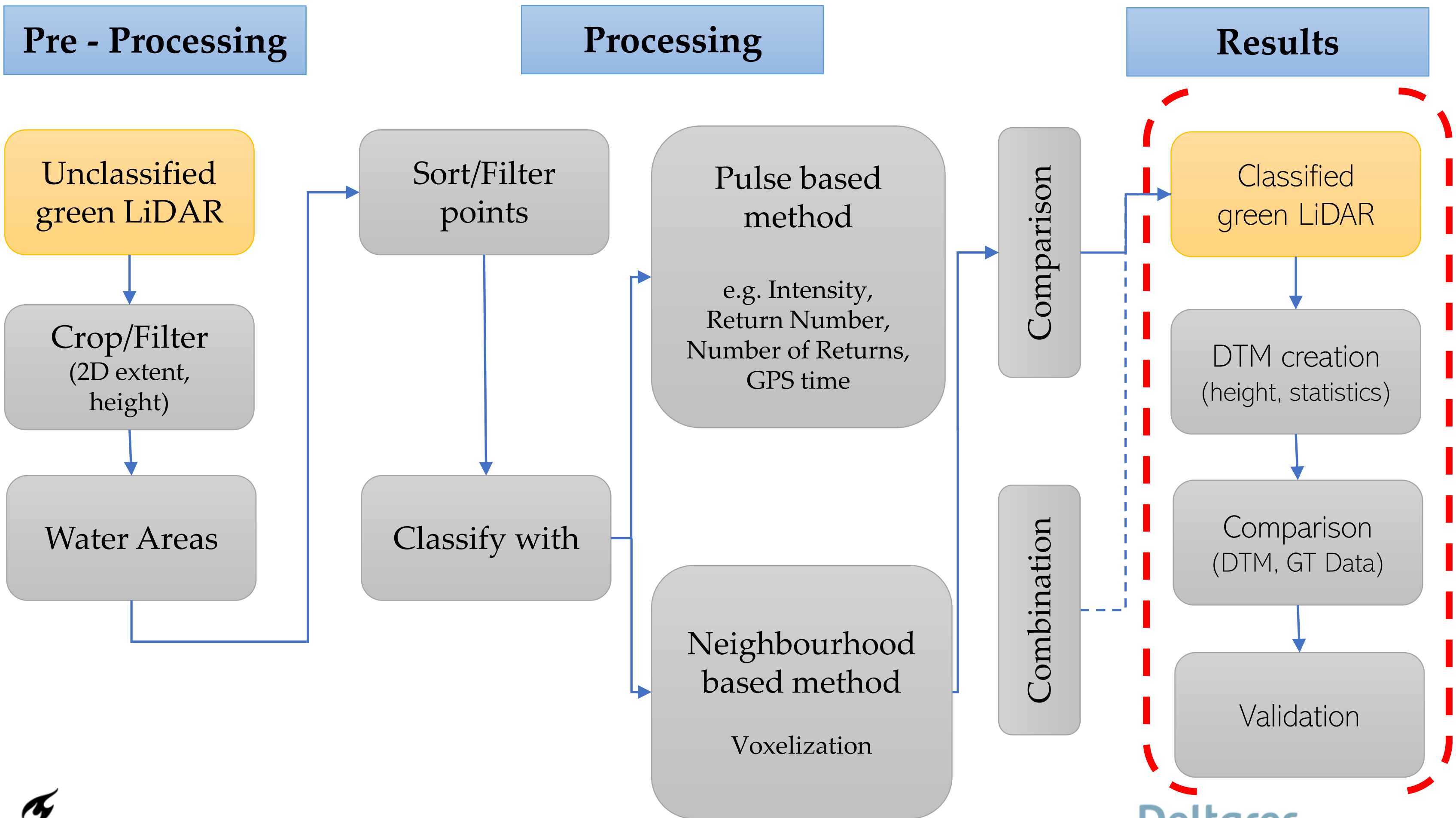
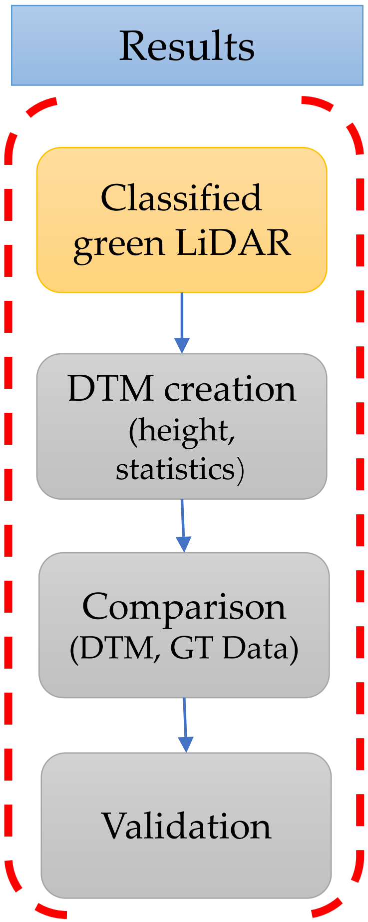
Methodology

Steps



Methodology

Steps

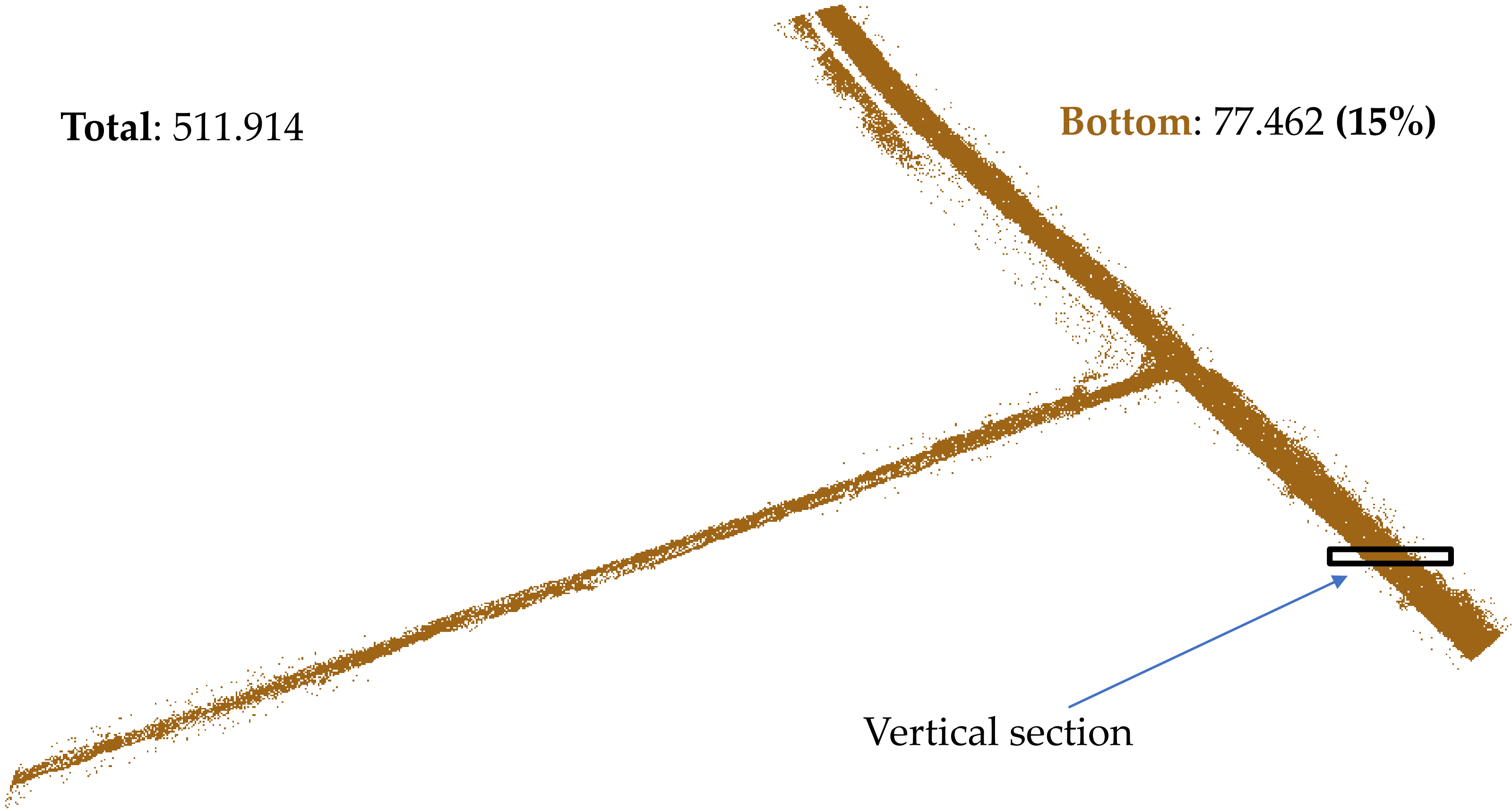


Classification

- **5 datasets**: 51NL1, 130NL2, 376NL3, 378Nl3, 199NL4
- Raster outputs (DTM) for both methods
- Comparison of rasterized GT Data and DTM rasters for datasets : 51NL1 & 199NL4

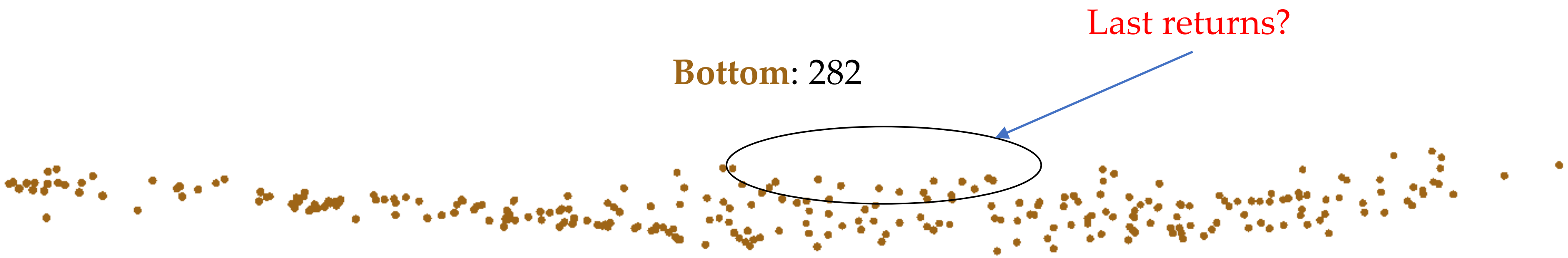
Pulse – based method

51NL1 Dataset



Pulse – based method

51NL1 Dataset



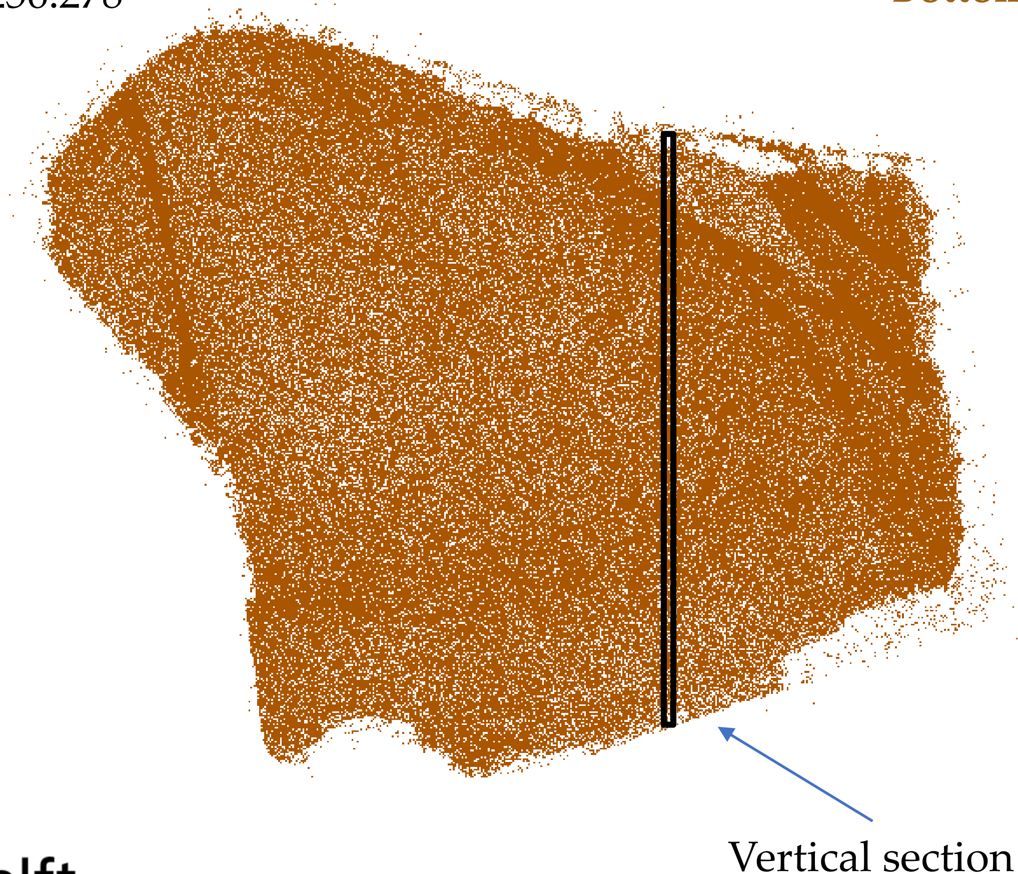
Vertical section (width:1m)

Pulse – based method

199NL4 Dataset

Total: 3.256.278

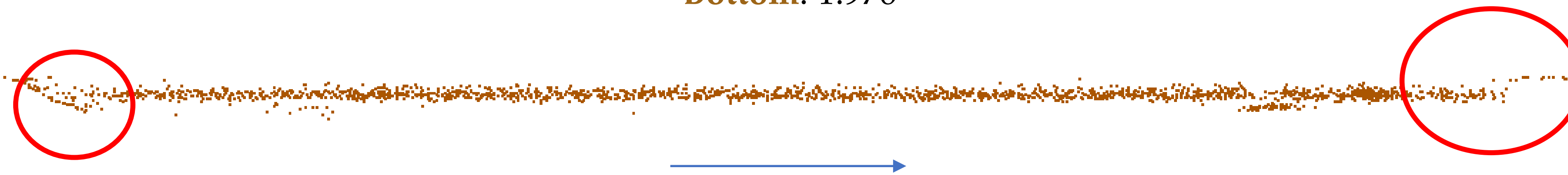
Bottom: 280.083 **(9%)**



Pulse – based method

199NL4 Dataset

Bottom: 1.976



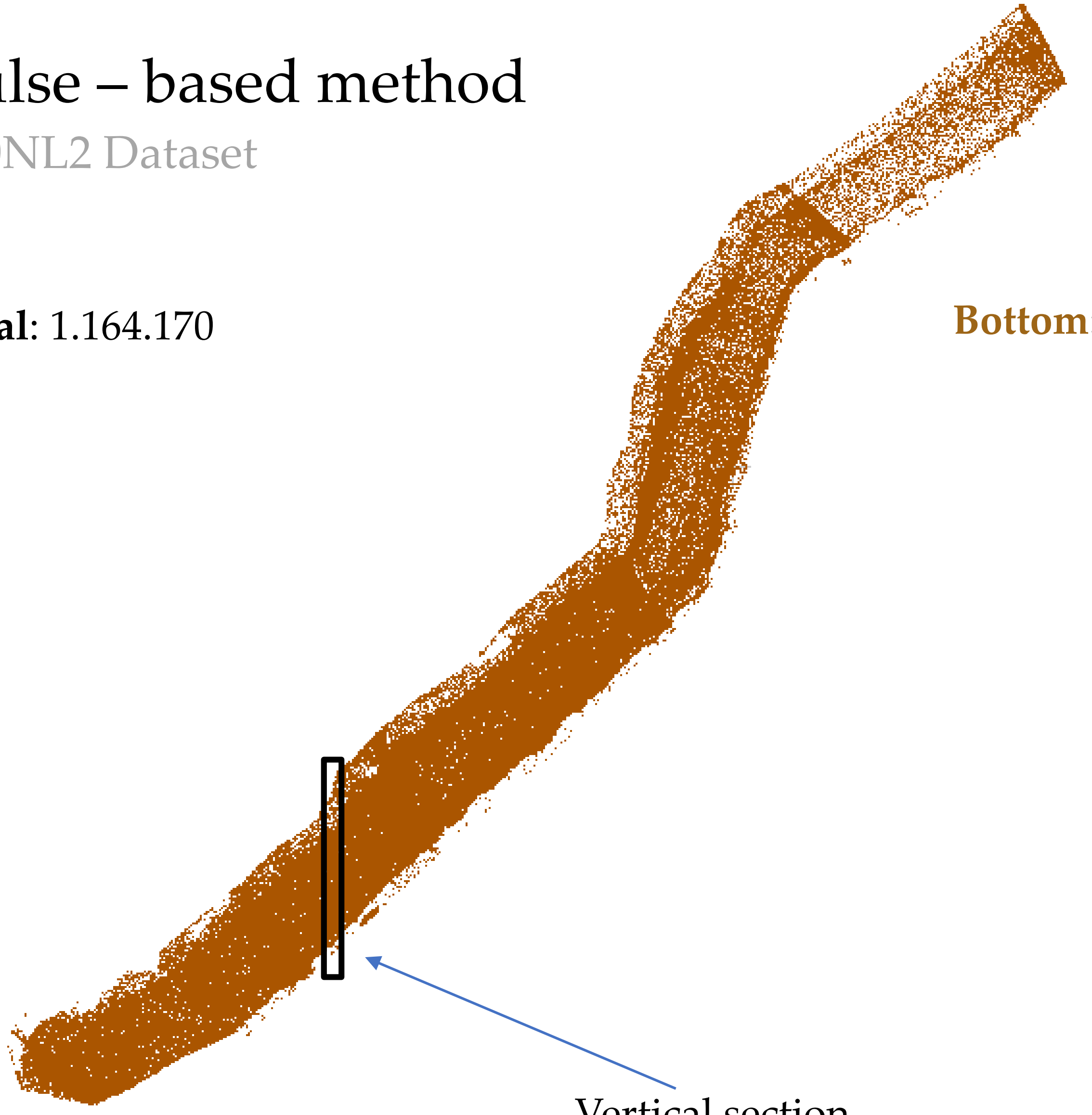
Vertical section (width:1m)

Pulse – based method

130NL2 Dataset

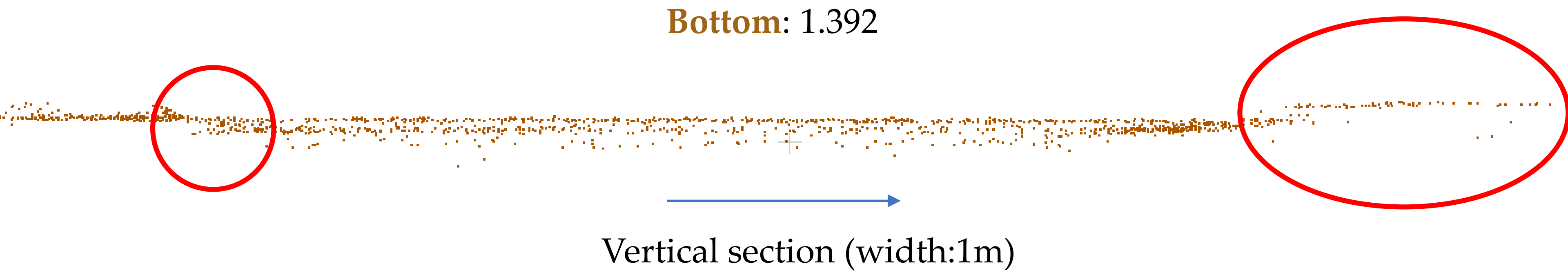
Total: 1.164.170

Bottom: 131.525 **(11%)**



Pulse – based method

130NL2 Dataset

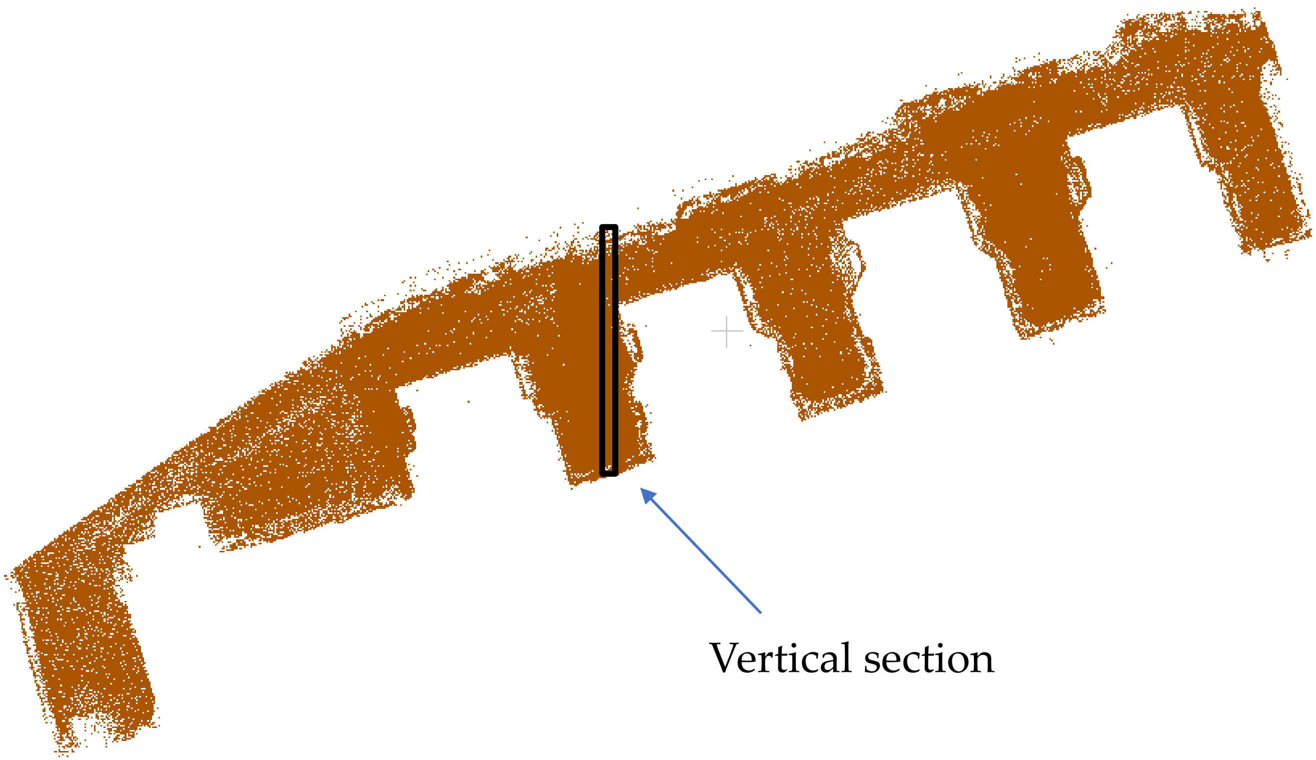


Pulse – based method

376NL3 Dataset

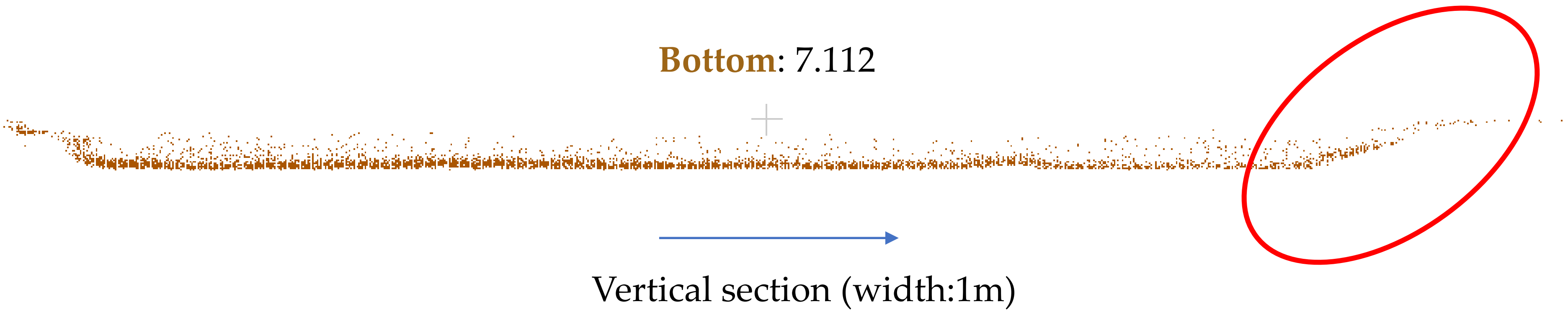
Total: 2.033.586

Bottom: 322.381 **(16%)**



Pulse – based method

376NL3 Dataset

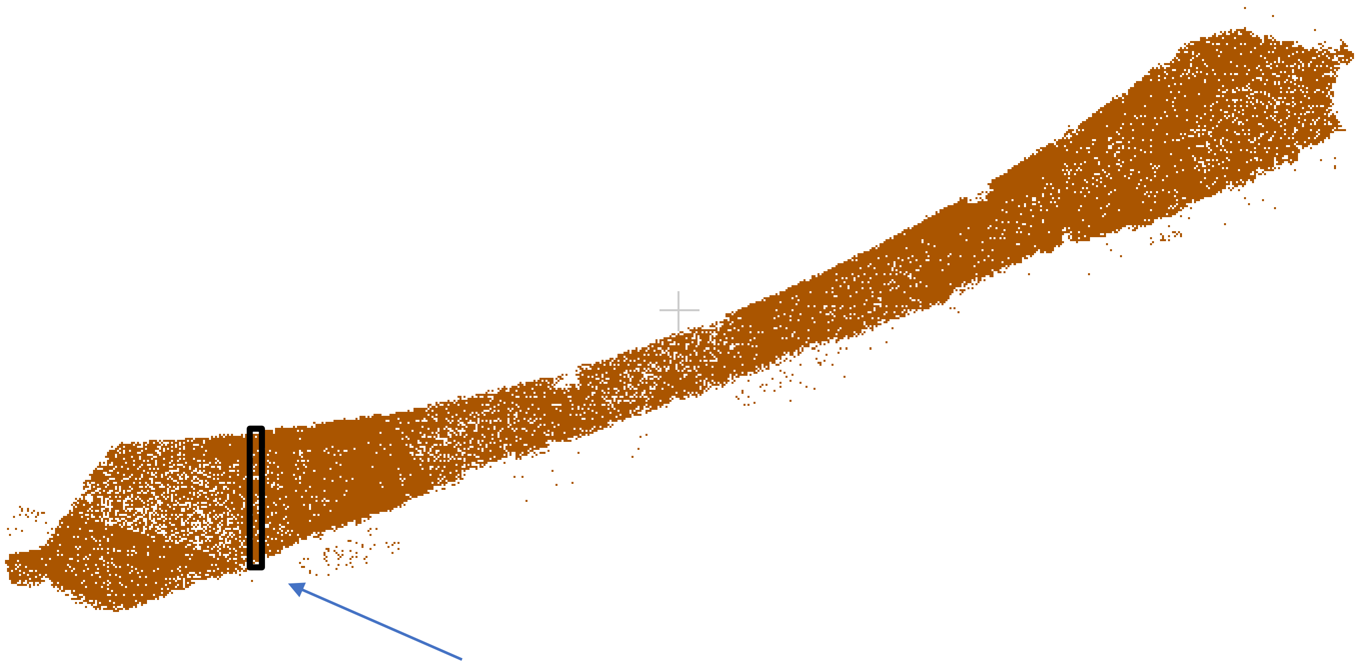


Pulse – based method

378NL3 Dataset

Total: 607.216

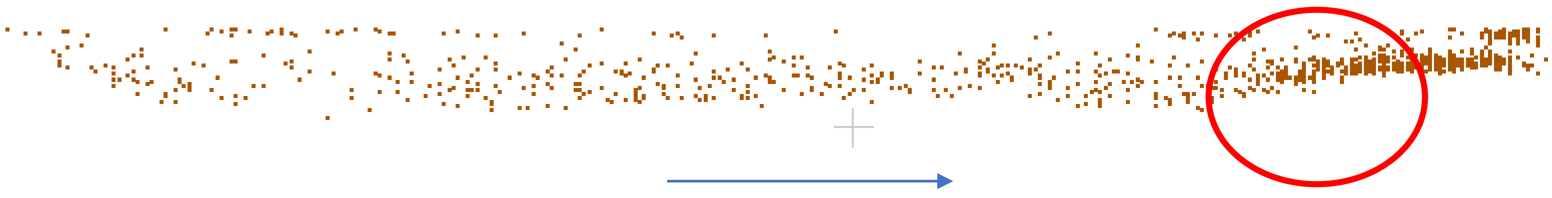
Bottom: 123.020 **(20%)**



Pulse – based method

378NL3 Dataset

Bottom: 1.443



Vertical section (width:1m)

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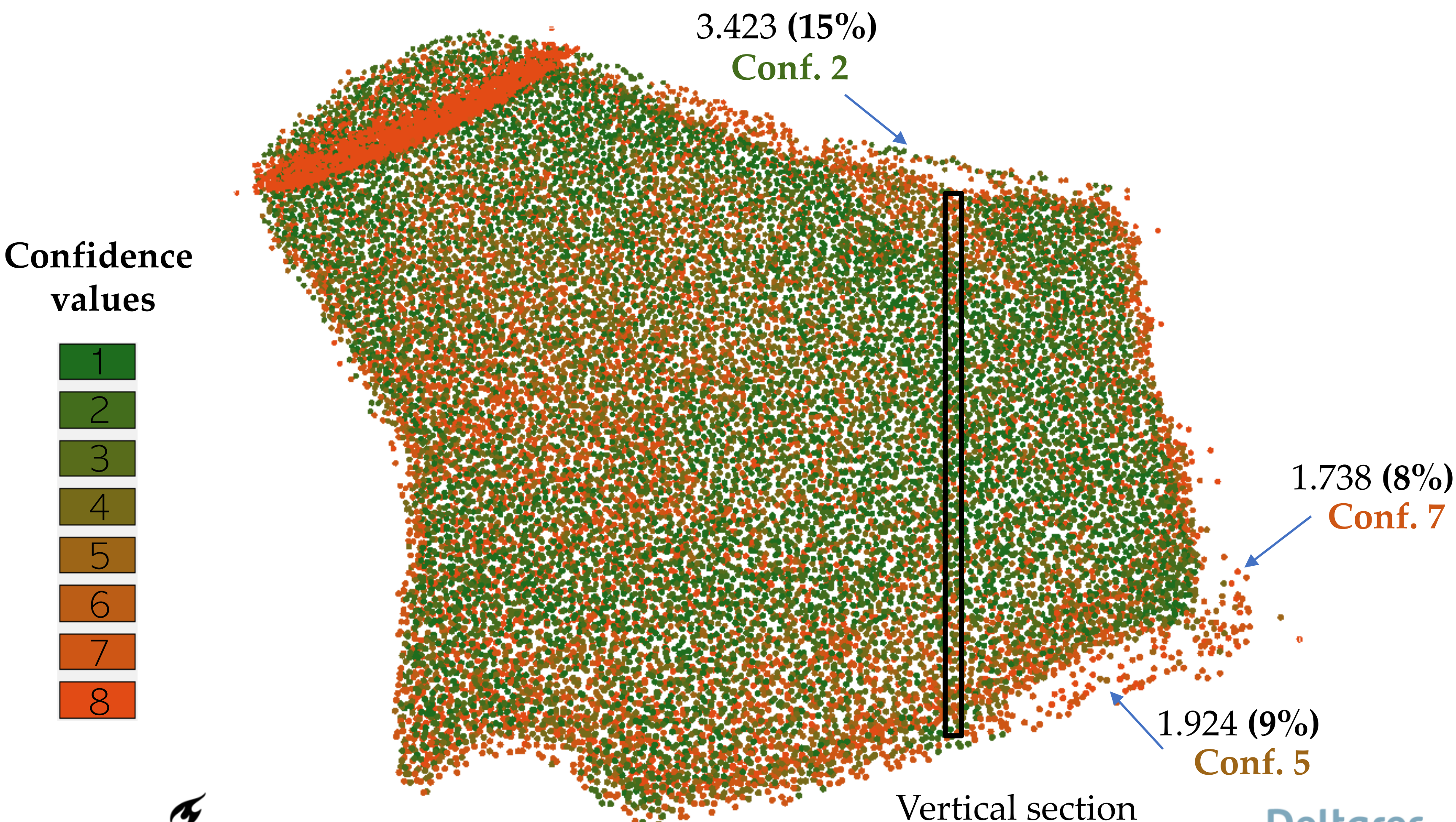
Voxel – based method

199NL4 Dataset – Bottom points

Voxel – size: 1m



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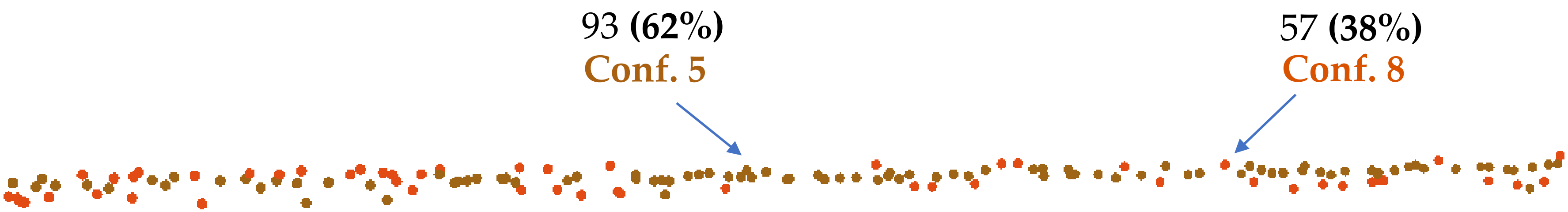
Voxel – based method

199NL4 Dataset – Bottom points (section)

Voxel – size: 1m



Vertical section

Parameters	*Mean*	*Median*
NormDensity	0,001	**0,004**
NormDistance	**0,25**	0
NormIntensity	0,194	**0,194**

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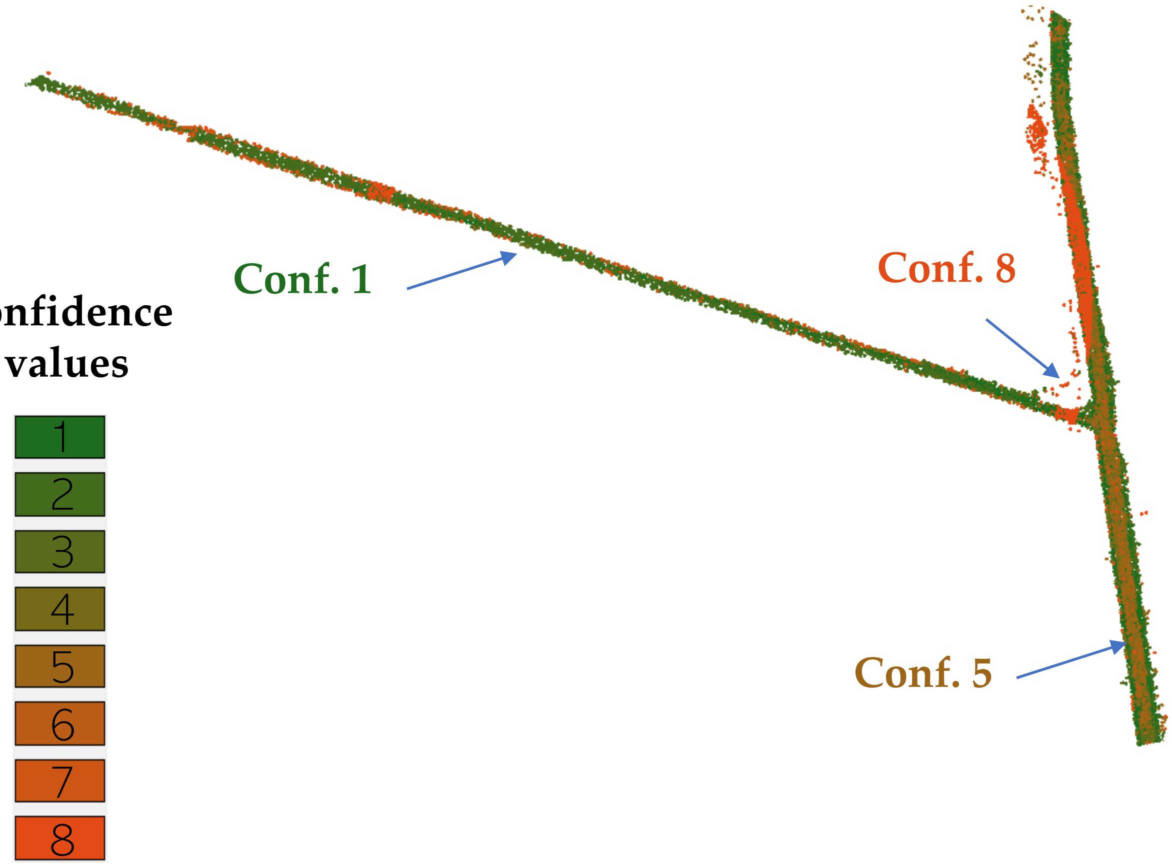
Deltares
Enabling Delta Life

Voxel – based method

51NL1 Dataset - Bottom points

Voxel – size: 1m

Confidence values



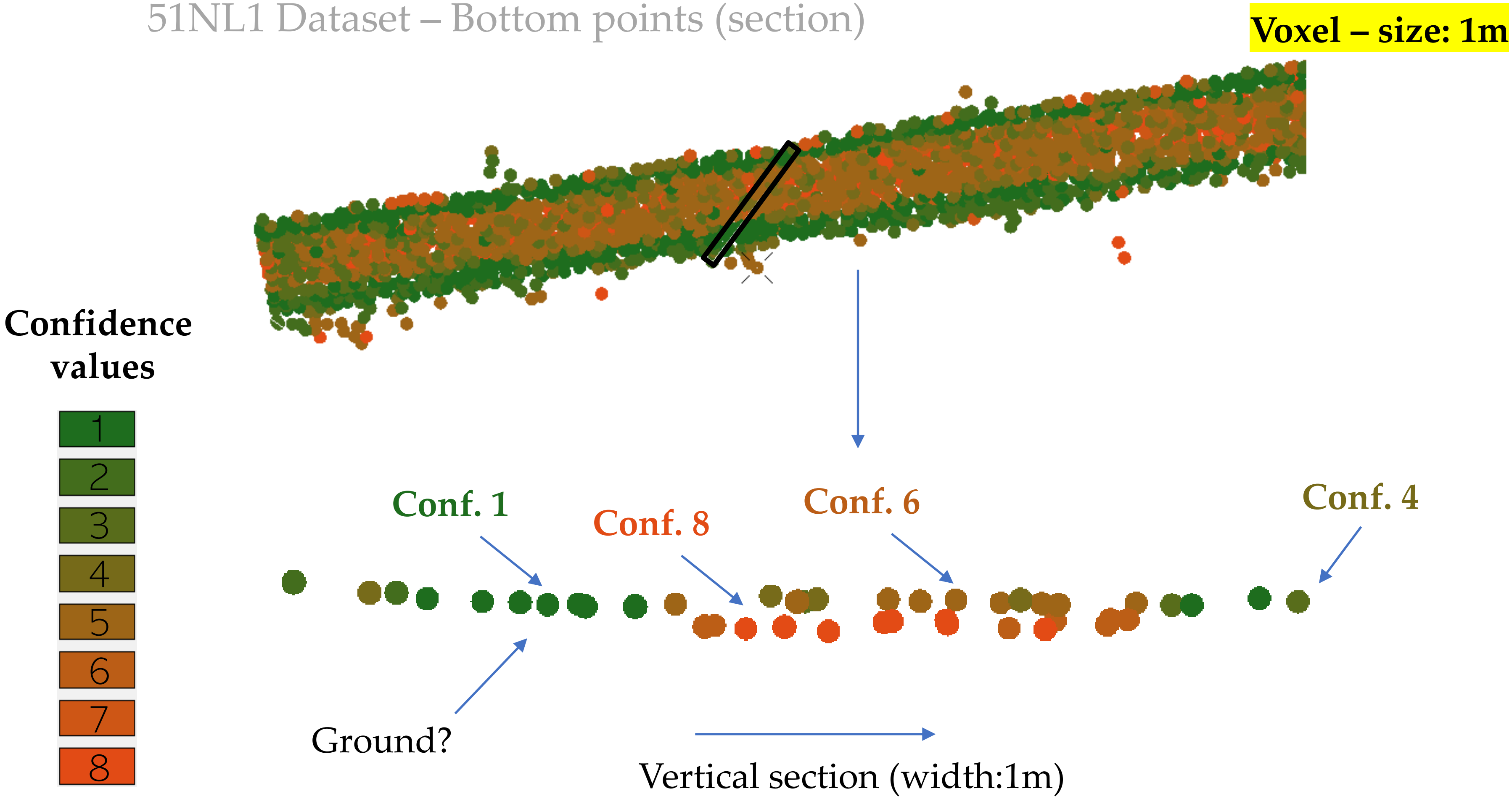
Conf. Values	Bottom Points	%
Conf.1	1.396	**15**
Conf.2	1.950	**20**
Conf.3	293	3
Conf.4	1.070	11
Conf.5	1.256	13
Conf.6	984	10
Conf.7	391	4
Conf.8	2.307	**24**
	9.647	

TU Delft

Deltares
Enabling Delta Life

Voxel – based method

51NL1 Dataset – Bottom points (section)



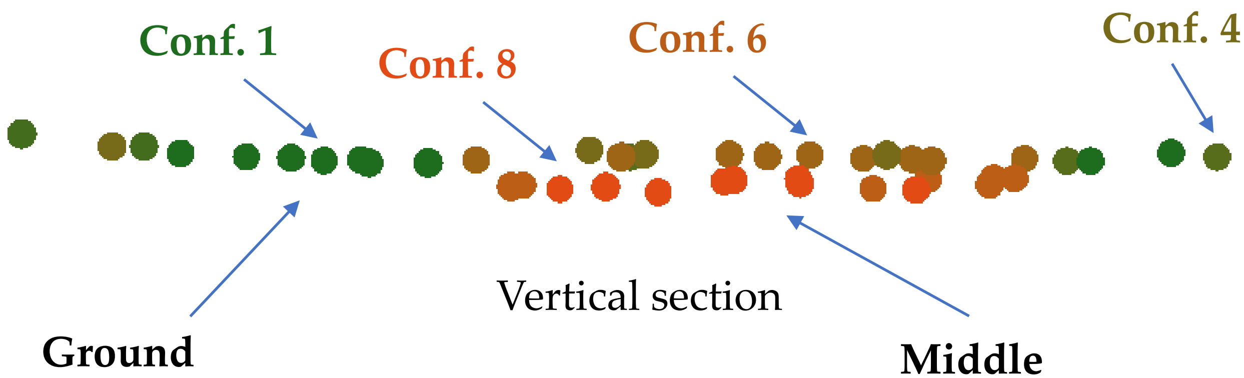
TU Delft

Deltares
Enabling Delta Life

Voxel – based method

51NL1 Dataset – Bottom points (section)

Voxel – size: 1m



Conf. Values	Bottom Points	%
Conf.1	1.396	**15,5**
Conf.2	1.950	**20**
Conf.3	293	0,03
Conf.4	1.070	11
Conf.5	1.256	13
Conf.6	984	10
Conf.7	391	0,04
Conf.8	2.307	24
	9.647	

Parameters	*Mean*	*Median*
NormDensity	7,81	**6**
NormDistance	**0,13**	0
NormIntensity	0,52	**0,6**

TU Delft

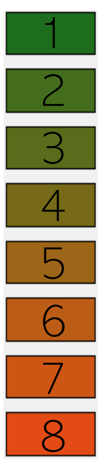
Deltares
Enabling Delta Life

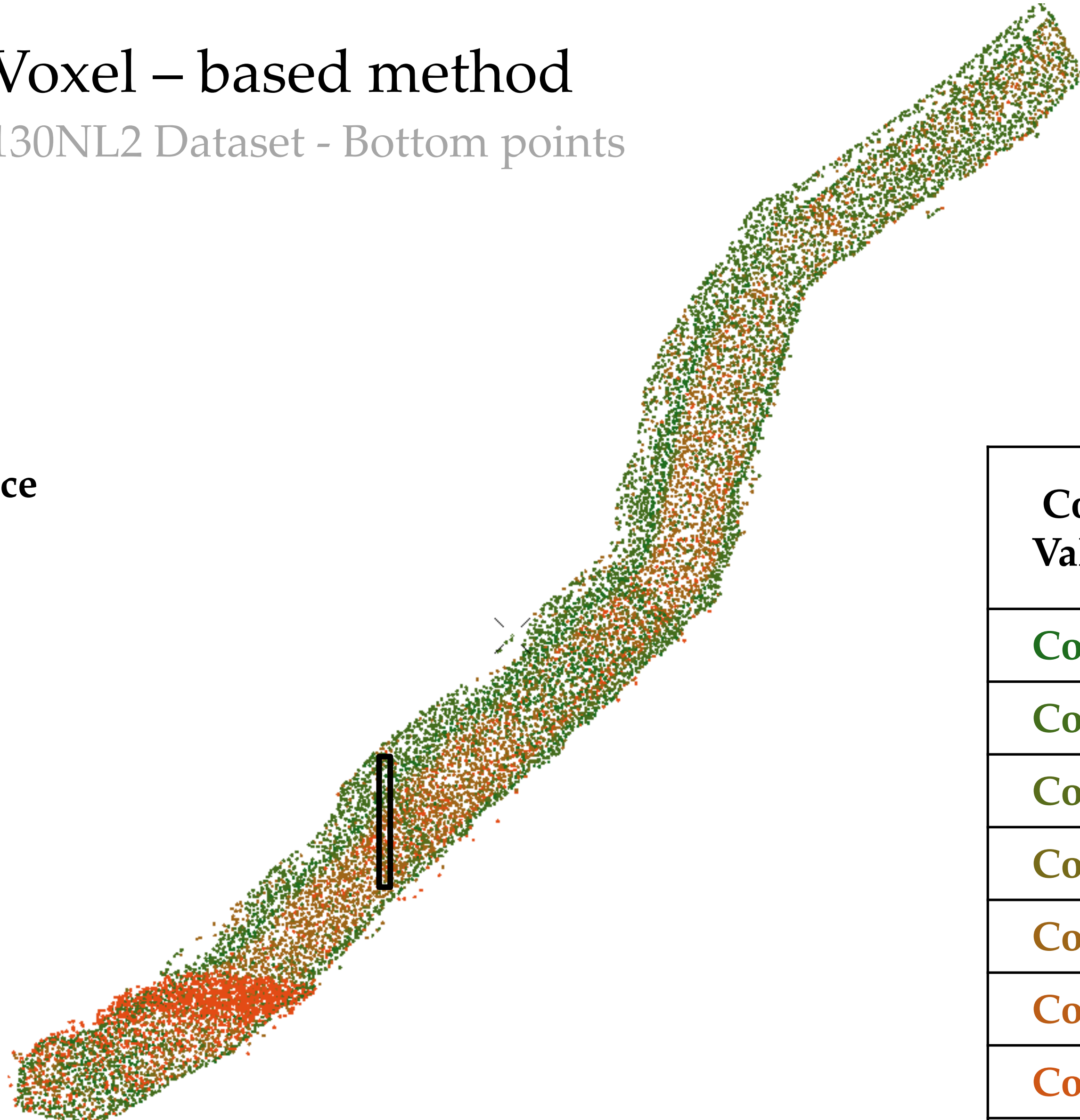
Voxel – based method

130NL2 Dataset - Bottom points

Voxel – size: 1m

Confidence values



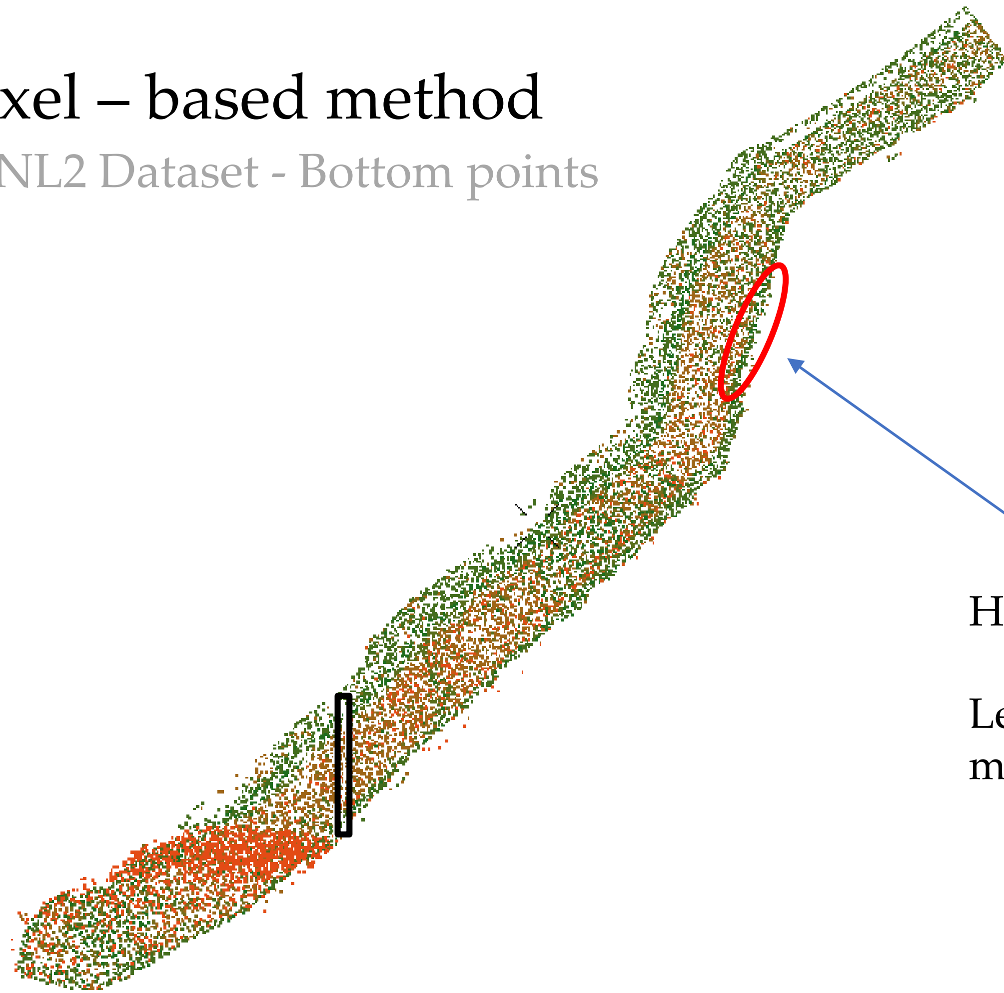


Conf. Values	Bottom Points	%
Conf.1	1.059	9
Conf.2	3.502	**30**
Conf.3	987	8,5
Conf.4	1.061	9
Conf.5	2.808	**24**
Conf.6	51	0,4
Conf.7	189	1,6
Conf.8	1.979	**17**
	11.636	

Voxel – based method

130NL2 Dataset - Bottom points

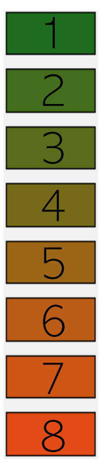
Voxel – size: 1m

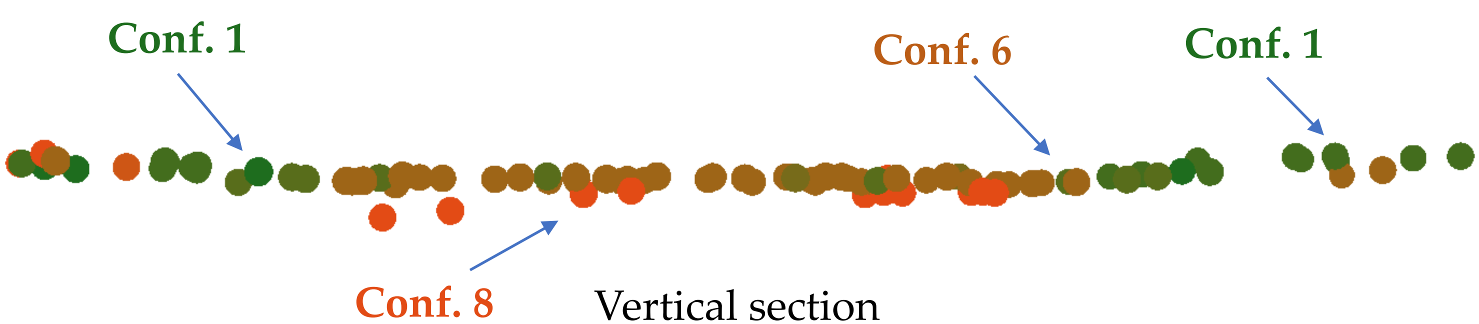


High confidence near shore

Less confidence in the middle part

Confidence values





Vertical section →

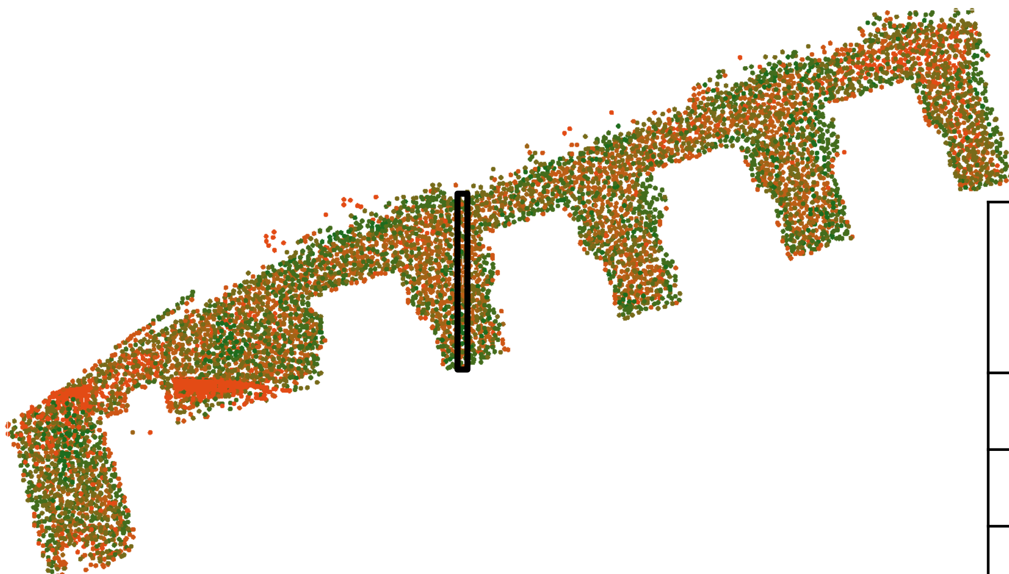
Voxel – based method

376NL3 Dataset - Bottom points

Voxel – size: 1m

Confidence values

1
2
3
4
5
6
7
8

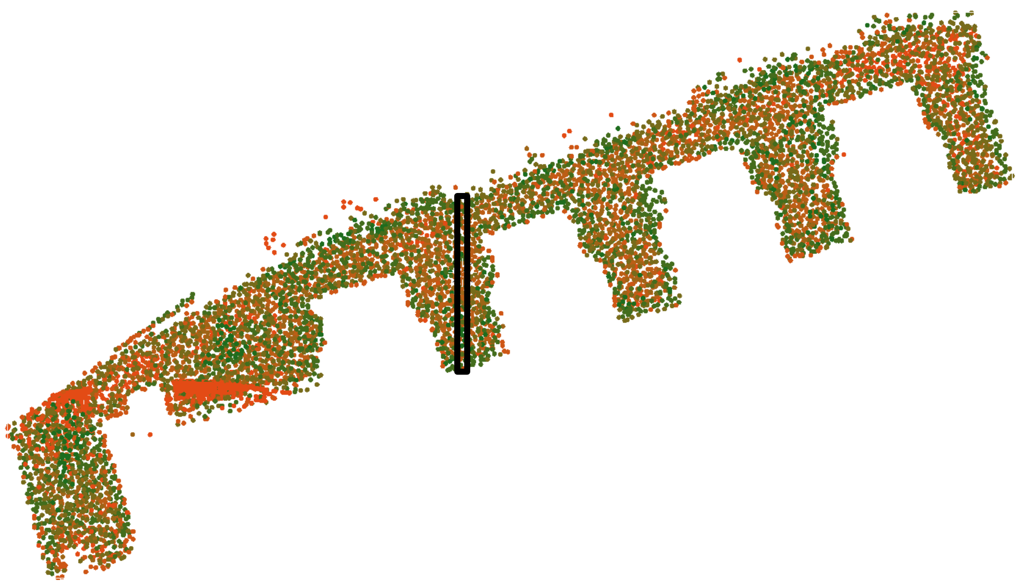


Conf. Values	Bottom Points	%
Conf.1	338	4
Conf.2	1.636	**20**
Conf.3	96	1,1
Conf.4	1.685	**20**
Conf.5	618	7,4
Conf.6	2.103	**25**
Conf.7	523	6,2
Conf.8	1.369	16,3
	8.368	

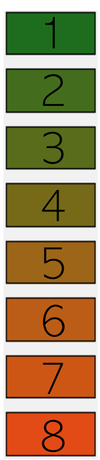
Voxel – based method

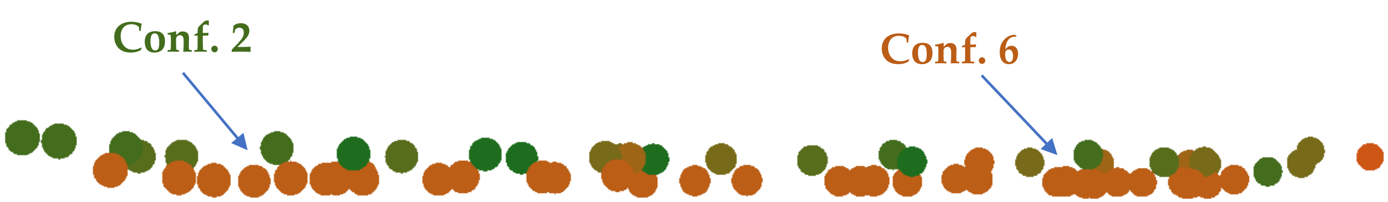
376NL3 Dataset - Bottom points

Voxel – size: 1m



Confidence values



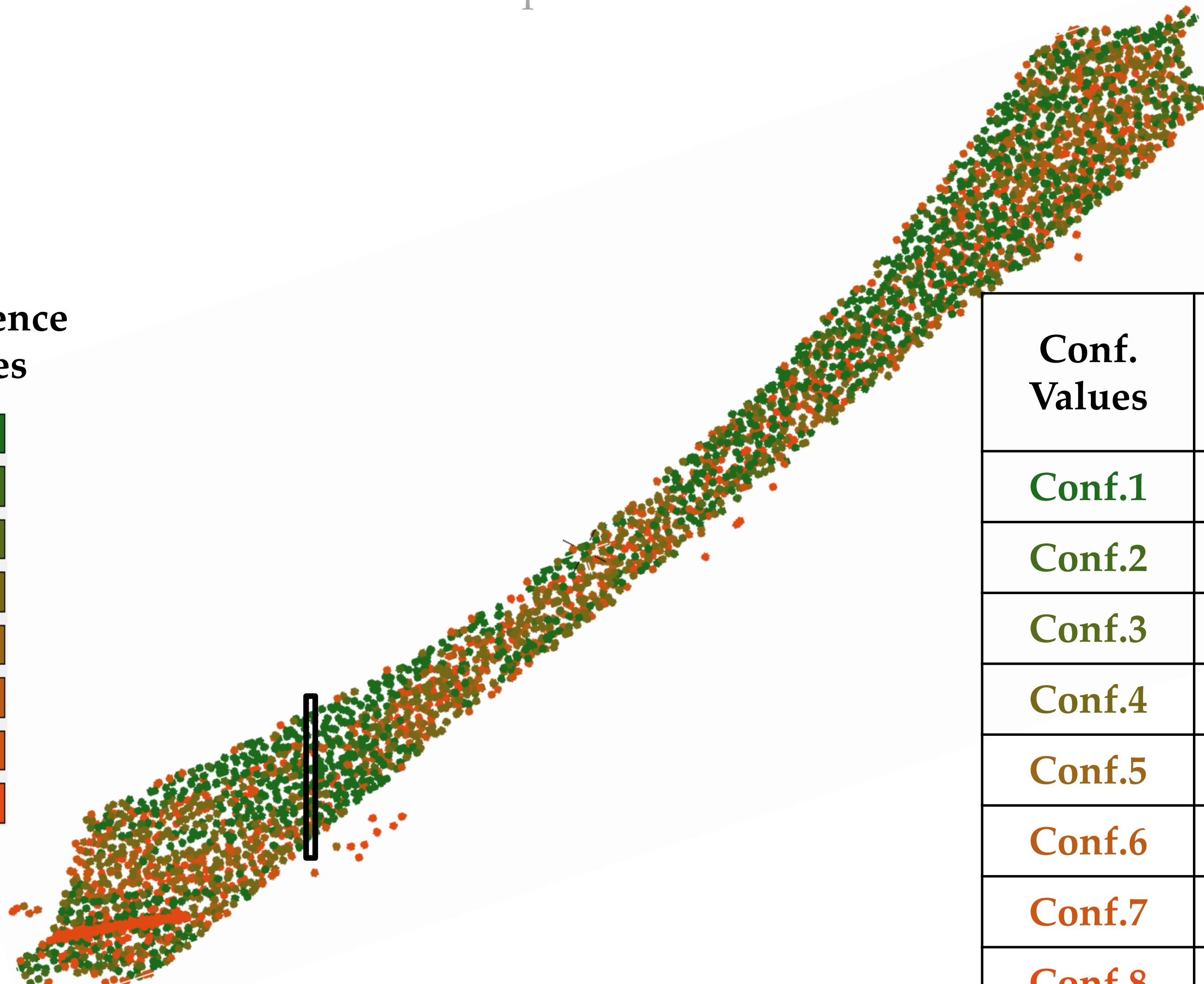


Vertical section →

Voxel – based method

378NL3 Dataset - Bottom points

Voxel – size: 1m



Confidence values

1
2
3
4
5
6
7
8

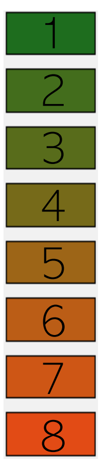
Conf. Values	Bottom Points	%
Conf.1	1.007	**27,5**
Conf.2	96	3
Conf.3	211	6
Conf.4	577	**15,5**
Conf.5	191	5
Conf.6	368	10
Conf.7	149	4
Conf.8	1.069	**29**
	3.668	

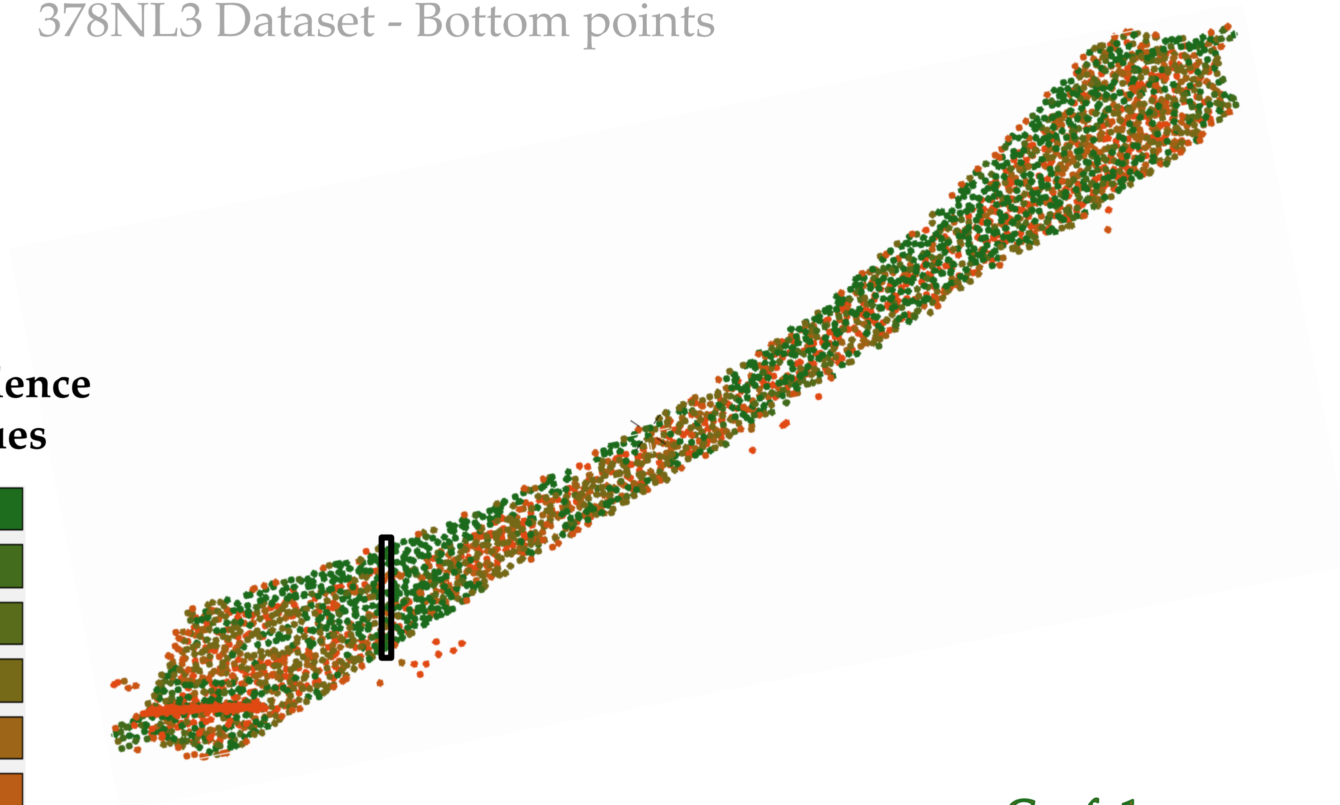
Voxel – based method

378NL3 Dataset - Bottom points

Voxel – size: 1m

Confidence values





Vertical section

Voxel – based method

To sum up

Voxel – size: 1m

Based on the density of the point cloud → more detected bottom points

Near the borders of waterbody → ground points (**Conf. 1-2**)

In the middle part of waterbody → less confident to be bottom (**Conf. 6-8**)

Name	*Total*	*Z_Range*	*Voxel size*	*Voxels*	*Bottom points*	*Point Density (points/m2)*
199NL4	2.851.512	1 to 4	1m x 1m	28.504	22.264	~215 - ~250
51NL1	391.309	-3,6 to -2,6	1m x 1m	13.048	9.647	~25 - ~100
130NL2	1.023.501	-2 to 0	1m x 1m	57.124	37.393	~35 - ~130
376NL3	1.872.542	-4,2 to -3	1m x 1m	10.163	8.368	~325 - ~660
378NL3	548.919	-4,5 to -3,3	1m x 1m	4.402	3.668	~250 - ~430

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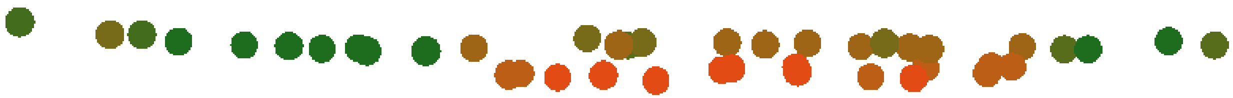
Comparison

51NL1 dataset

Voxel – size: 1m

Section points: **42**
Section width: 1m

Voxel - based method



Pulse - based method

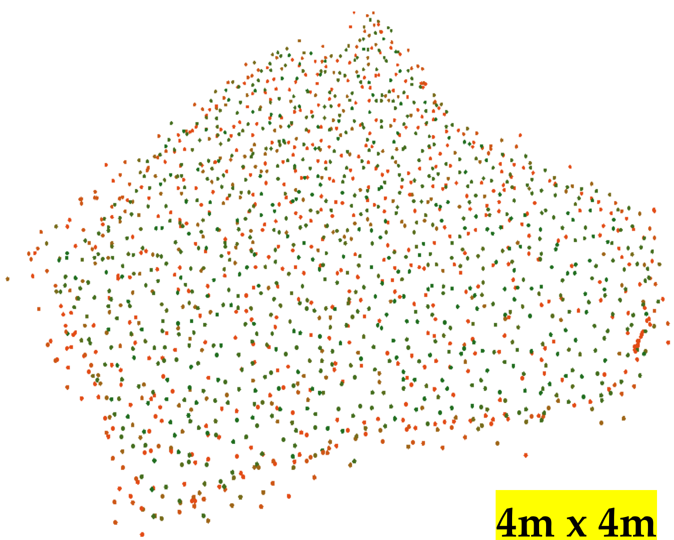
Section points: **282**
Section width: 1m

Voxel – based method

199NL4 Dataset - Different voxel sizes

Various voxel sizes

Name	*Total*	*Voxel size*	*Voxels*	*Bottom points*	*Time (sec)*
199NL4	2.851.512	2m x 2m	7.458	6.152	525
199NL4	2.851.512	3m x 3m	3.417	2.902	300
199NL4	2.851.512	4m x 4m	1.916	1.705	187

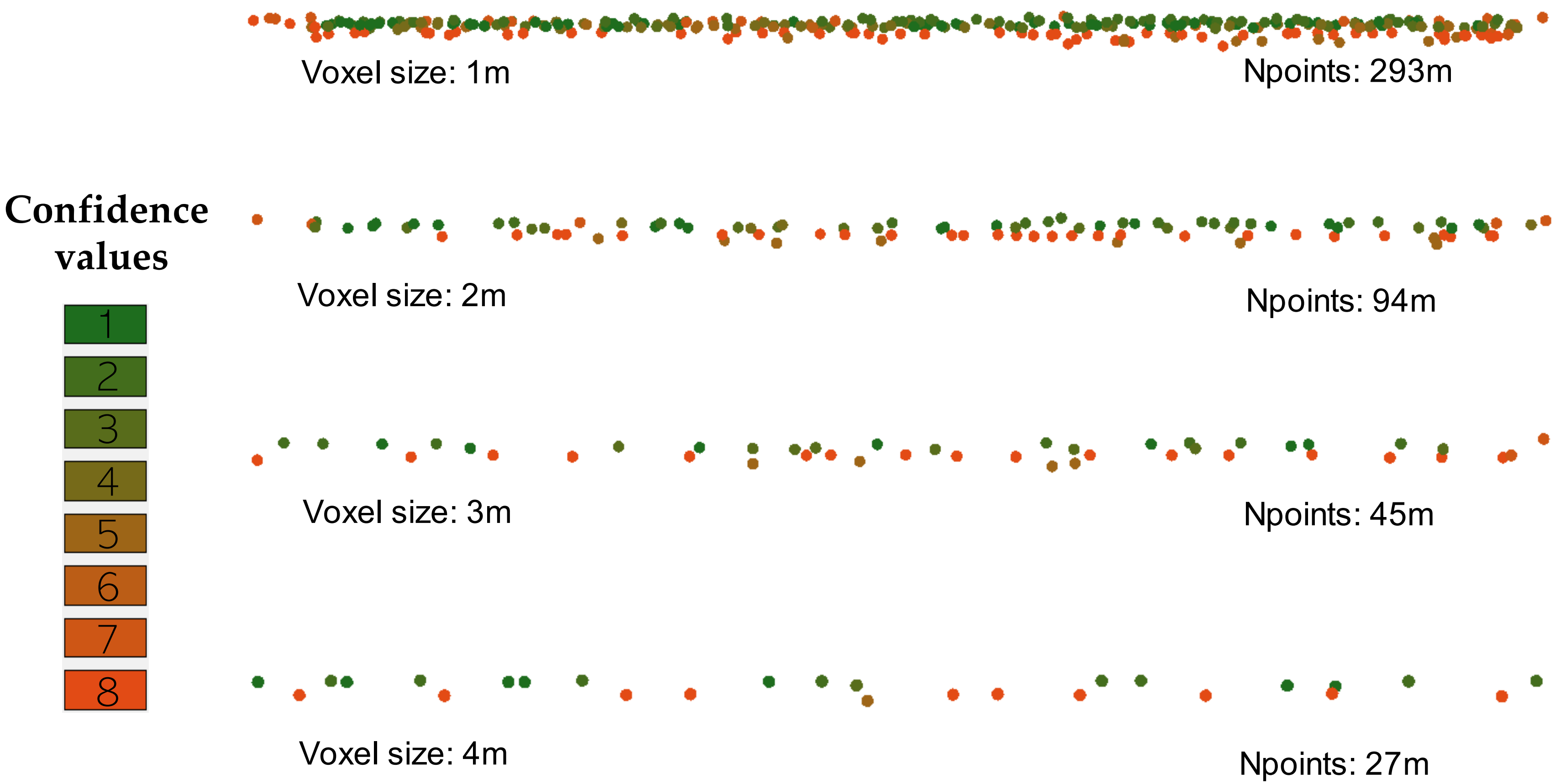


4m x 4m

Voxel – based method

199NL4 Dataset – Bottom points

Various voxel sizes



Voxel – based method

51NL1 Dataset - Different voxel sizes

Various voxel sizes

Name	*Time (sec)*
51NL1	105
51NL1	65
51NL1	48

4m x 4m

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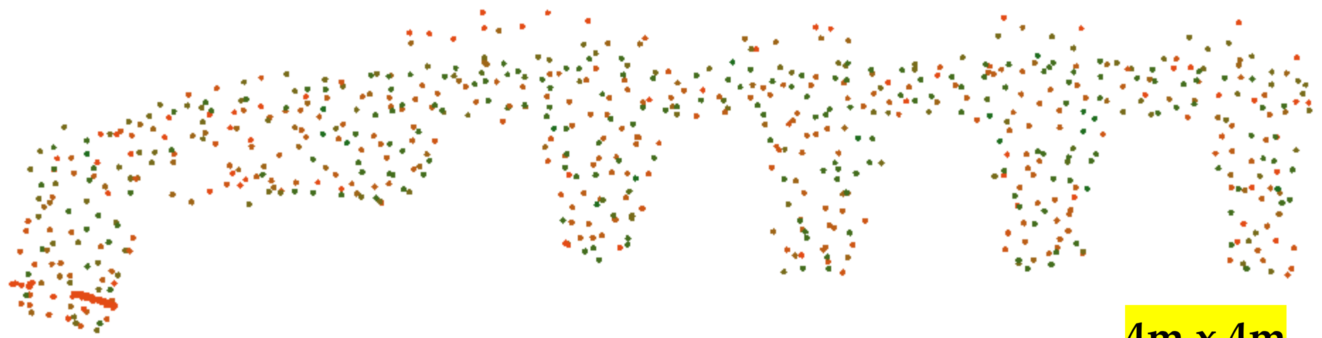
Voxel – based method

376NL3 Dataset - Different voxel sizes

Various voxel sizes

Name	*Total*	*Voxel size*	*Voxels*	*Bottom points*	*Time (sec)*
376NL3	2.033.586	2m x 2m	2.868	2.419	107
376NL3	2.033.586	3m x 3m	1.416	1.232	49
376NL3	2.033.586	4m x 4m	862	766	30



4m x 4m

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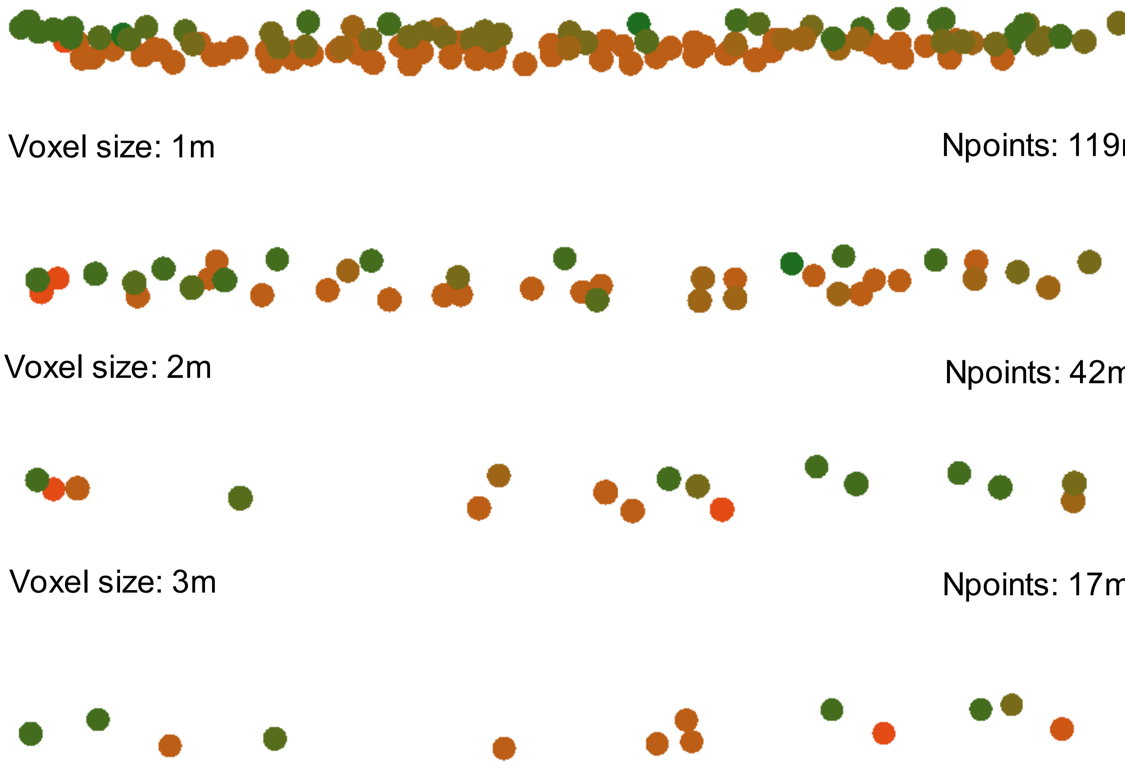
Voxel – based method

376NL3 Dataset - Different voxel sizes – Sections

Various voxel sizes

Confidence values



Voxel size: 1m

Npoints: 119m

Voxel size: 2m

Npoints: 42m

Voxel size: 3m

Npoints: 17m

Voxel size: 4m

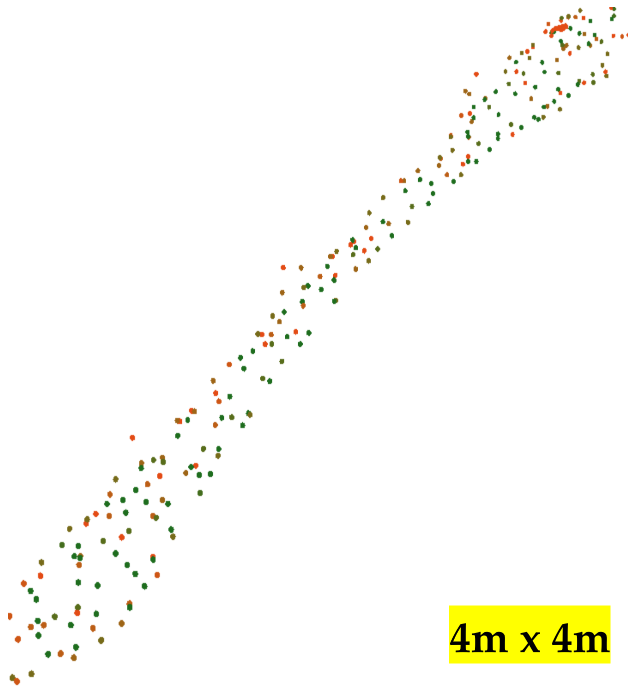
Npoints: 13m

Voxel – based method

378NL3 Dataset - Different voxel sizes

Various voxel sizes

Name	*Total*	*Voxel size*	*Voxels*	*Bottom points*	*Time (sec)*
378NL3	607.216	2m x 2m	1.272	929	44
378NL3	607.216	3m x 3m	637	439	25
378NL3	607.216	4m x 4m	397	292	12



4m x 4m

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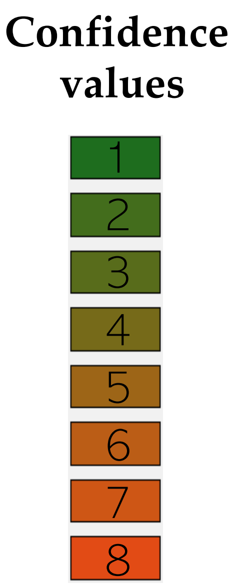
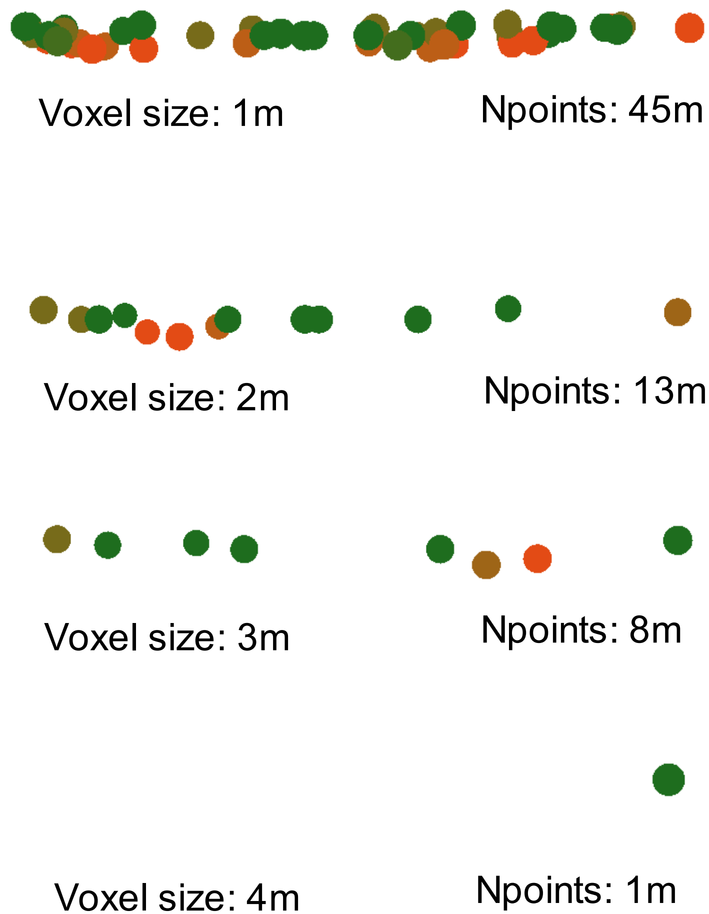
Voxel – based method

378NL3 Dataset - Different voxel sizes – Sections

Various voxel sizes



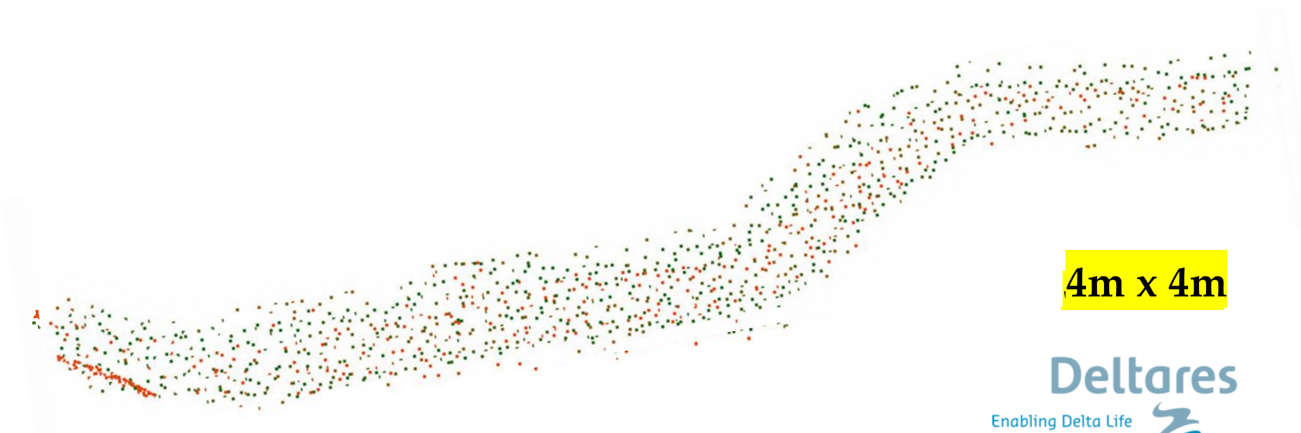


Voxel – based method

130NL2 Dataset - Different voxel sizes

Various voxel sizes

Name	*Total*	*Voxel size*	*Voxels*	*Bottom points*	*Time (sec)*
130NL2	1.164.170	0.5m x 0.5m	57.124	37.393	1.326
130NL2	1.164.170	2m x 2m	5.320	3.836	150
130NL2	1.164.170	3m x 3m	2.665	1.960	85
130NL2	1.164.170	4m x 4m	1.620	1.272	62



4m x 4m

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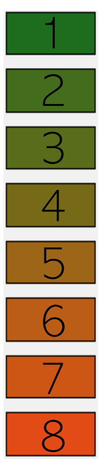
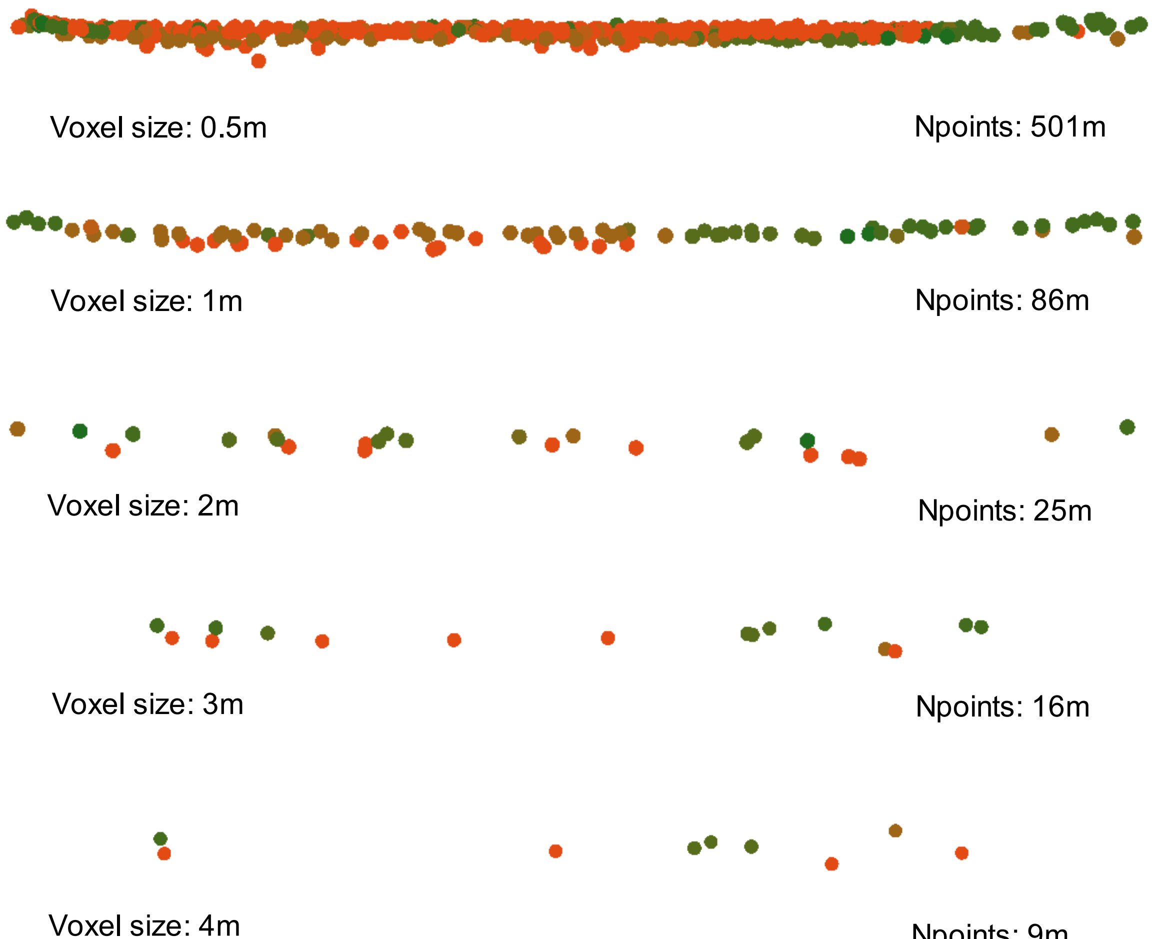
Voxel – based method

130NL2 Dataset - Different voxel sizes – Sections

Various voxel sizes

Confidence values





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Voxel – based method

To sum up

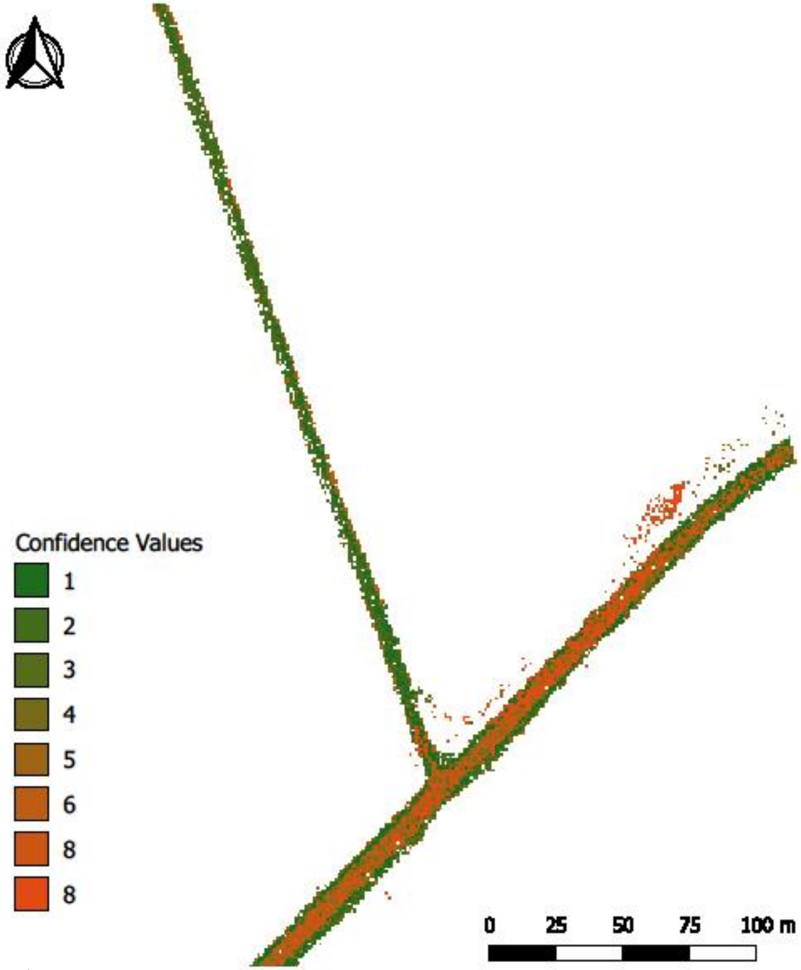
Various voxel sizes

- As the voxel size increases, less bottom points are detected
- Voxel size (**0,5m**) → too many points → unnecessary (!?)
- Voxel size **>2m** (most cases) → Sparse distribution of points

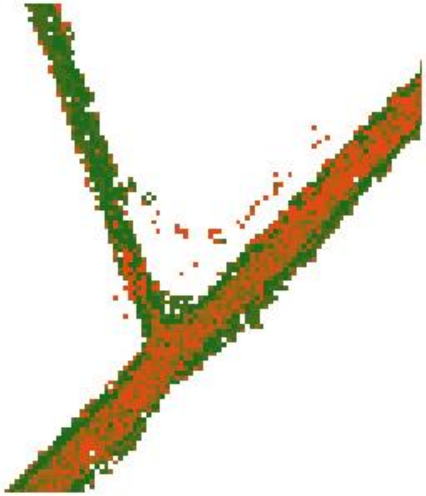
  → Bottom surface reconstruction becomes difficult
- In 378NL3 with voxel size 4m → just **one** bottom point
- The computation time increases rapidly, as the voxel size increases

Rasterization

51NL1 Dataset – DTM – Voxel approach



Rasterized bottom points of the water body 51_NL1, categorized by confindence values



Pixel size (0.5m)

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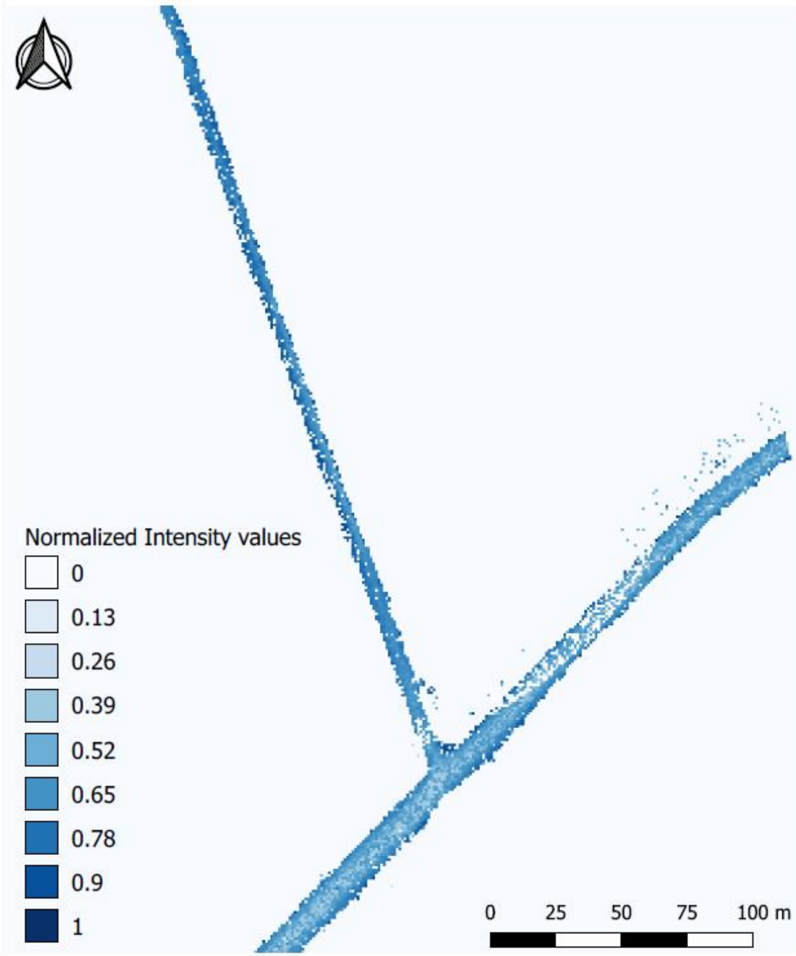
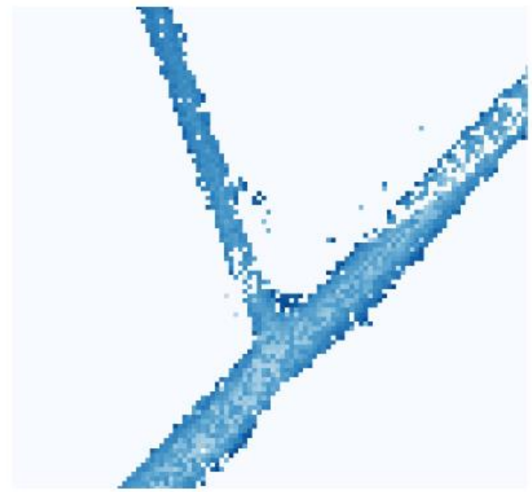
Rasterization

51NL1 Dataset – DTM – Voxel approach

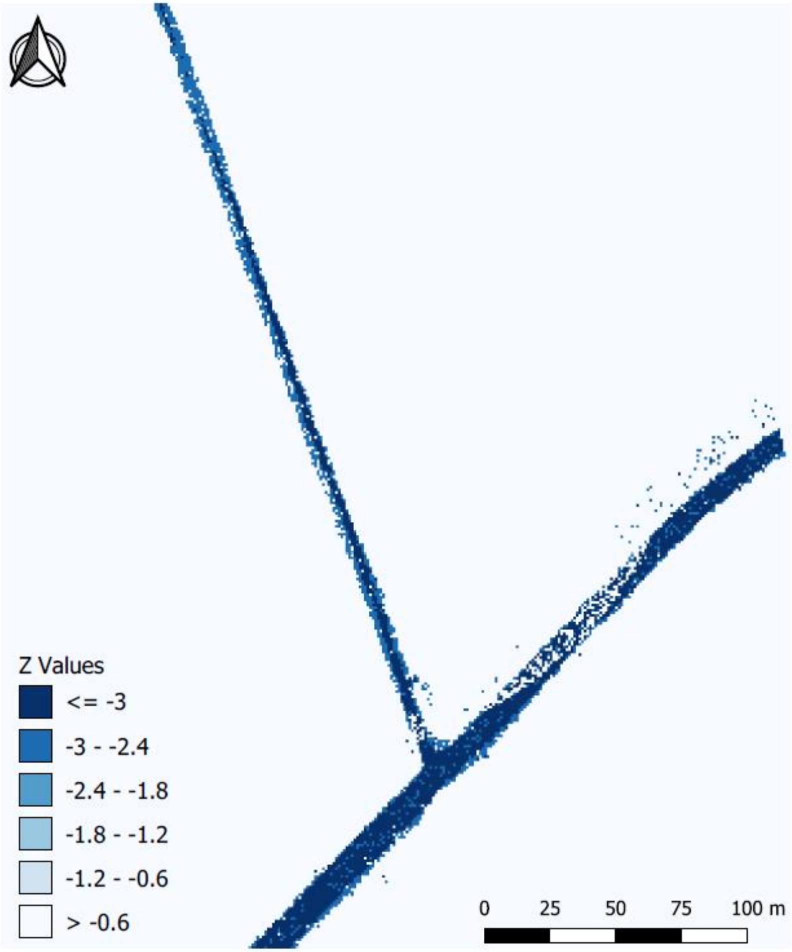


Rasterized bottom points of the water body 51_NL1, categorized by normalized intensity values

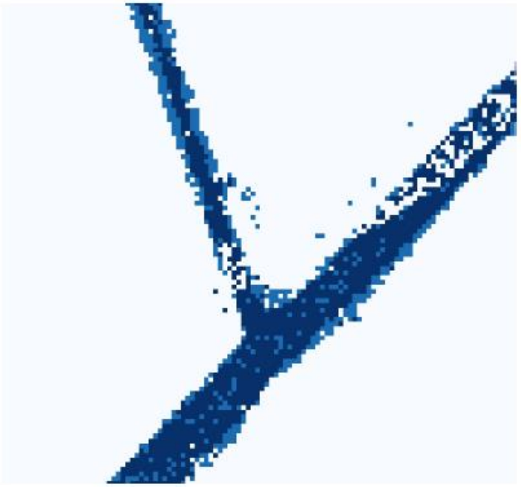


Rasterization

51NL1 Dataset – DTM - Voxel approach



Rasterized bottom points of the water body 51_NL1, categorized by z values

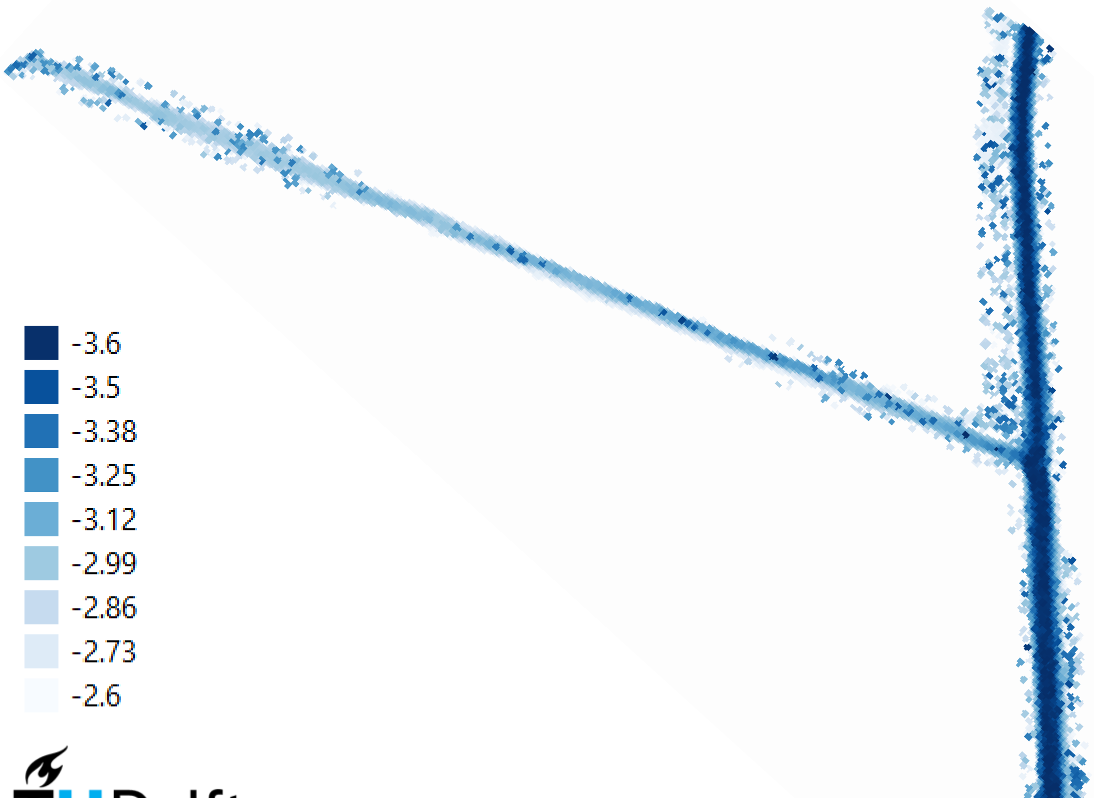


Voxel – based method:

- Rasterized z values
  - Pixel size (0.5m)

Rasterization

51NL1 Dataset – DTM - Pulse approach



Pulse – based method:

- Rasterized z values
- Pixel size (0.5m)

TU Delft

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Enabling Delta Life

Validation

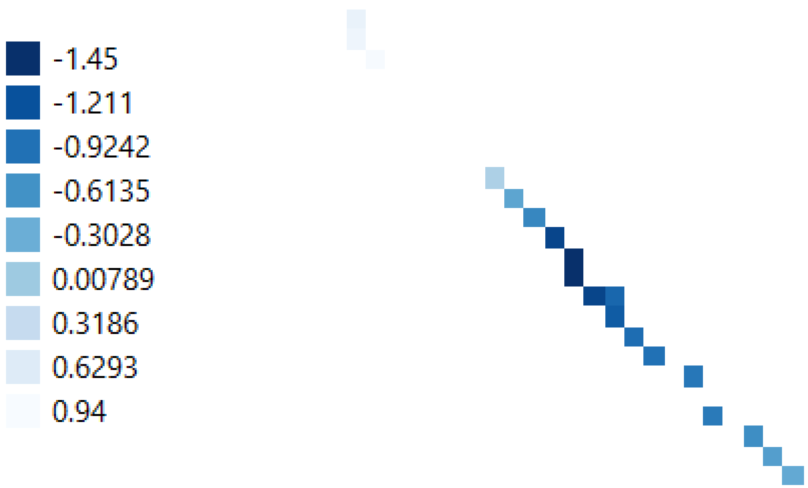
51NL1 Dataset: Pulse – based method VS GtD

Z Differences (m)

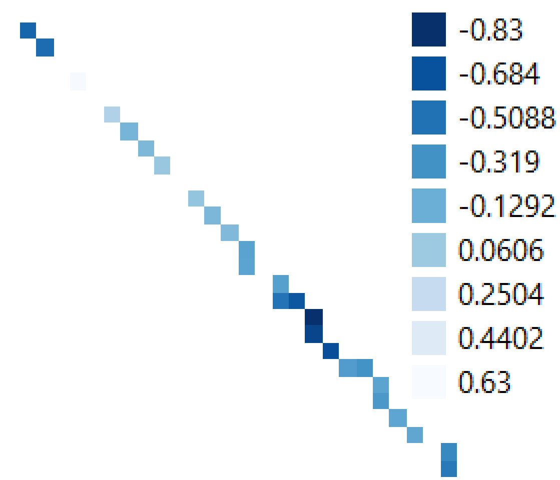
Validation

51NL1 Dataset : Pulse – based method VS GtD

Profile Section 3



Profile Section 4

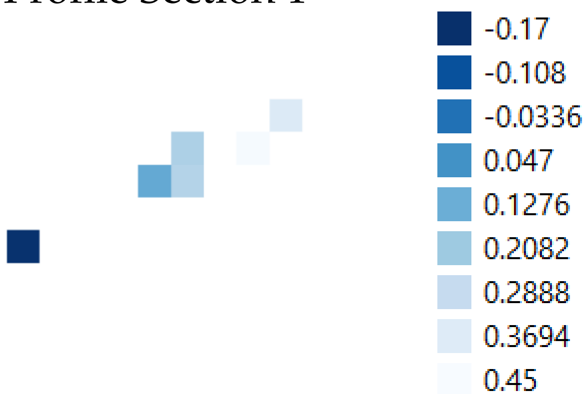


Z Differences (m)

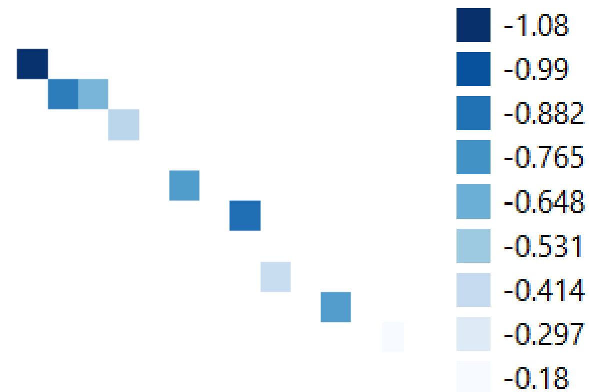
Validation

51NL1 Dataset : Voxel – based method VS GtD

Profile Section 1

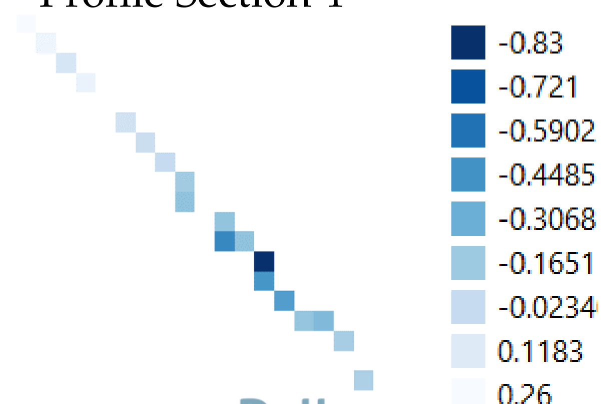


Profile Section 2



Profile Section 3

Profile Section 4



Z Differences (m)

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Validation

51NL1 Dataset

Prof. Section 1	Z Differences (m)	
Points	p3	p5
Actual Z (m)	-3,33	-2,60
Pulse-based	0,21	0,19
Voxel-based	0,24	0,17

Range: 21cm – 49 cm

Range: 11cm – 44 cm

Prof. Section 2	Z Differences (m)	
Points	p4	p5
Actual Z (m)	-1,90	-1,90
Pulse-based	-1,20	-1,20
Voxel-based	1,07	-1,07

Range: 7 cm - 1,2 m

Range: 40cm -1,07m

Using Point Sampling Tool

TU Delft

Deltares Enabling Delta Life

Validation

51NL1 Dataset

Range:
84cm – 1,4m
14cm – 1,22m

Prof. Section3	Z Differences (m)								
Points	p1	p2	p8	p9	p11	p14	p16	p18	p21
Actual Z (m)	-3,58	-2,83	- 2,54	-2,46	-2,55	-2,47	-2,48	-2,03	-1,93
Pulse-based	0,94	0,13	0,65	0,72	0,87	1,0	1,11	1,29	1,50
Voxel-based	0,97	0,14	0,55	0,64	0,84	0,96	0,96	1,09	1,23

Range:
20cm – 73cm
20cm – 83cm

Prof. Section4	Z Differences (m)								
Points	p2	p3	p4	p6	p7	p8	p11	p12	p15
Actual Z (m)	-3,6	3,47	- 3,45	-2,54	-3,34	-2,73	-2,95	-2,88	-2,68
Pulse-based	0,05	0,06	0,08	0,19	0,2	0,25	0,5	0,5	0,69
Voxel-based	0,2	0,08	0,21	0,11	0,2	0,19	0,5	0,5	0,39

Using Point Sampling Tool

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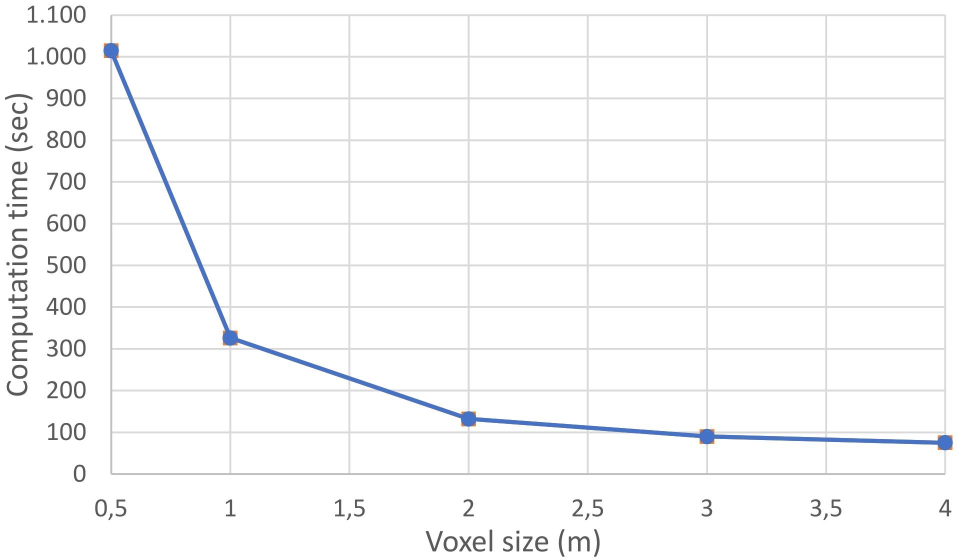
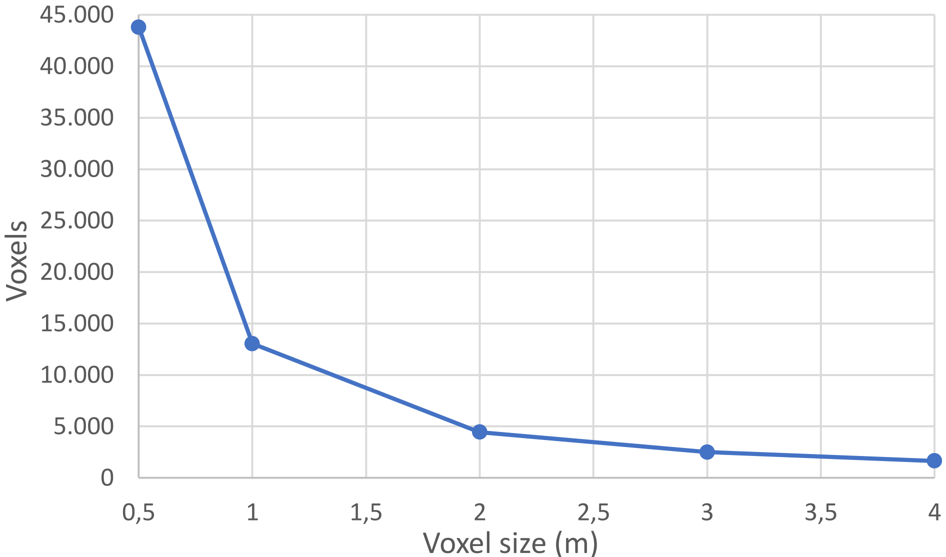
Computation time

51NL1 Dataset – half million points





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Deltares
Enabling Delta Life

To sum up

- Bottom points can be partially detected using both methods
- **Less** bottom points in the voxel – approach due to the voxel size, but **more accurate** compared to the ground truth data (GtD)
- The z differences (**GtD vs Voxel**) vary from few centimeters (11cm) to more than a meter (1,3m) in the four profile sections
- **More** points detected as bottom in the pulse – based method, but **less accurate**
- The z differences (**GtD vs Pulse**) vary from (20cm) to (1,4m).
- Refraction correction has not been applied and can influence the accuracy
- Different voxel sizes might affect the classification result

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Deltares
Enabling Delta Life

Research Questions & Conclusions

q2: Can pulse and/or neighbourhood - based methods in a green ALB be used to classify and detect the bottom points?
- **Both methods managed to classify the water bodies; especially their bottom points.**

q3: What is the influence of different voxel resolutions for classification, in terms of accuracy and computation load?
- **Smaller than 0,5m voxel size results to unpractical computation time, but bigger number of voxels. Various point density in a voxel influences the running time.**

q4: How does the various point cloud quality (i.e. density, outliers) affect the classification process?
- **Outliers affect the pulse-based approach as many points do not correspond to a pulse.**
- **Density affects the computation time.**

q5: Can a confidence value of water bodies be calculated? If it is possible, how?
- **Yes, based on density, distance and intensity parameters.**

TU Delft

Deltares
Enabling Delta Life

Research Questions & Conclusions

Q1: Can the bottom points of shallow and muddy water-bodies in the Netherlands be automatically detected using ALB?

Yes, using both methods. The result depends on:

- the **density** of a water body
- the presence of **outliers** during the pre-processing steps
- the right trade – off between **voxel size** and **running time**

Except the pre-processing steps, the procedure is **automated.**

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Recommendations for future work

- Deep learning algorithms on point cloud (e.g. PointNet++)
- Pre-processing automation
- Ground filtering
- Test more datasets with extreme cases

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Thank you for your attention!