TECHNISCHE UNIVERSITÄT DRESDEN

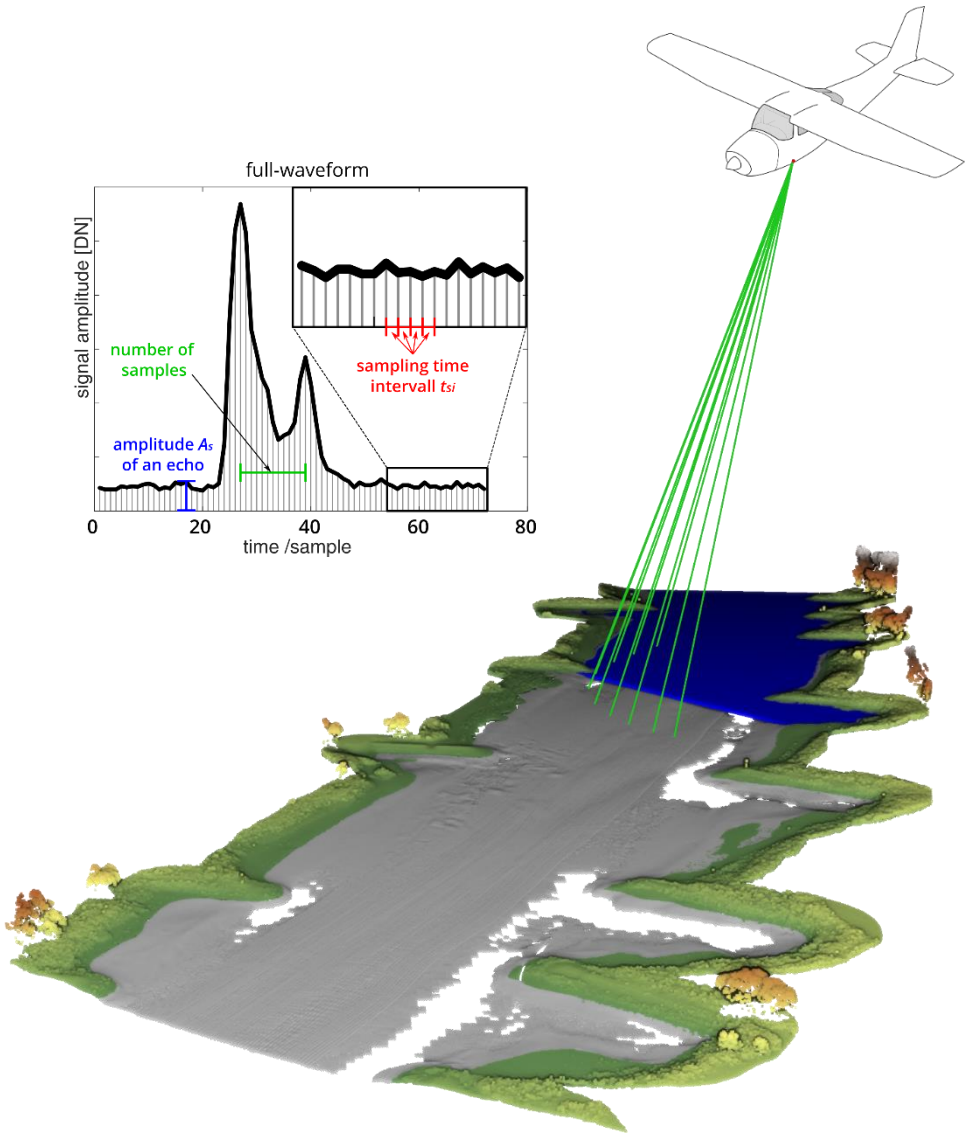
DRESDEN concept

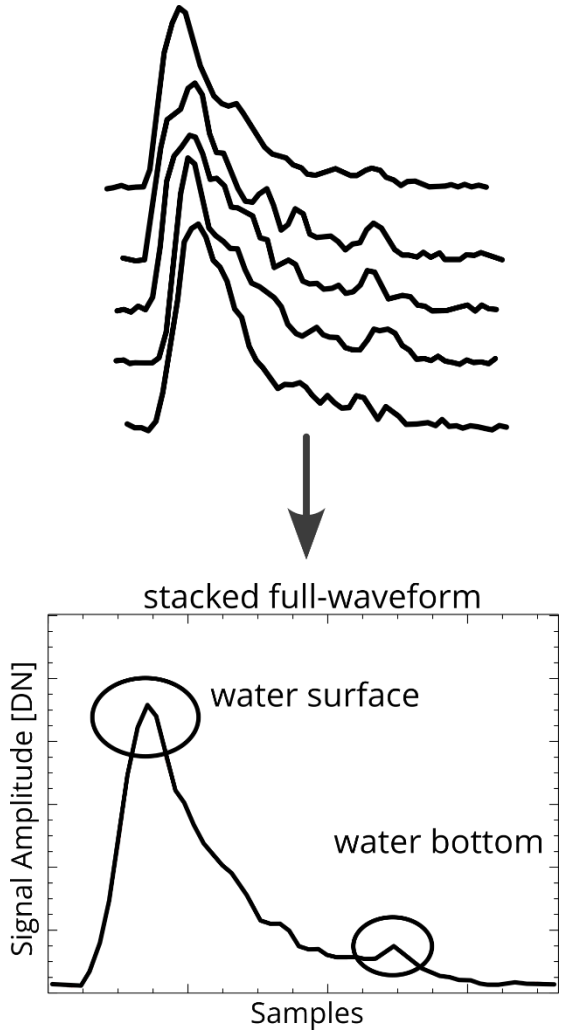
**Institute of Photogrammetry and Remote Sensing**
Chair of Photogrammetry

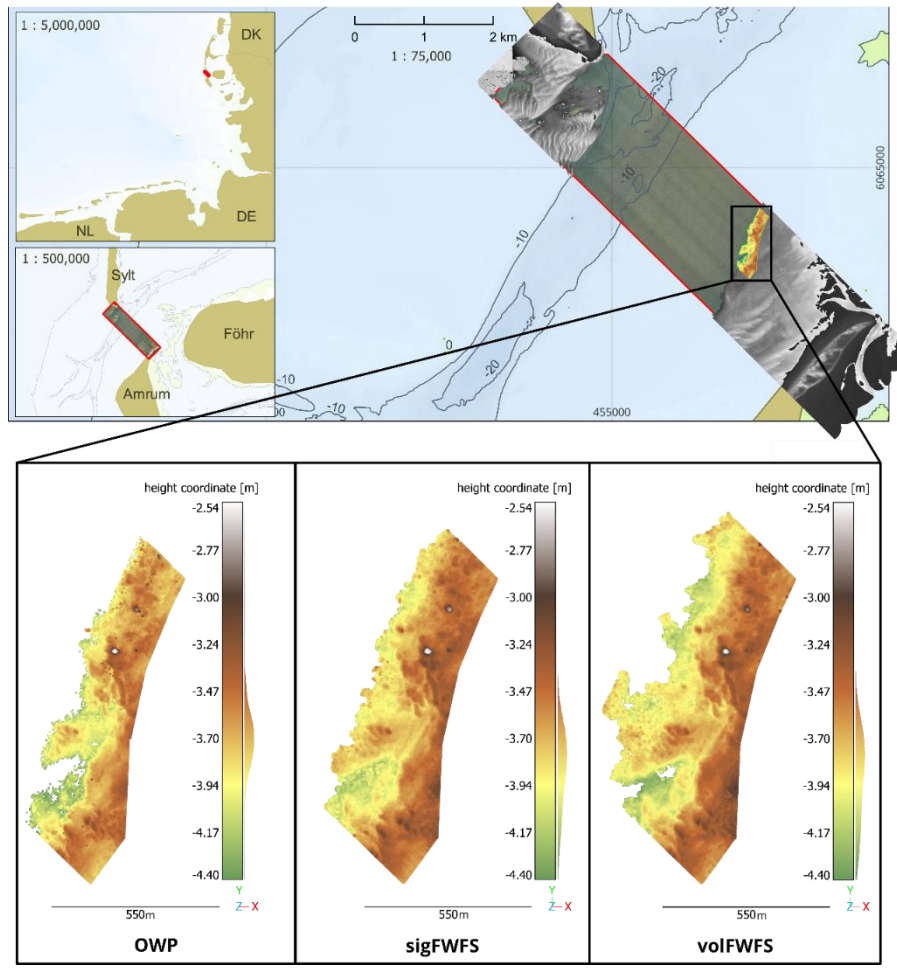
# Full-waveform stacking techniques applied to coastal LiDAR bathymetry data

David Mader, Katja Richter, Patrick Westfeld, Hans-Gerd Maas
HYDRO2024, Rostock-Warnemünde, 05 Nov 2024

# Content


full-waveform
signal amplitude [DN]
number of samples
amplitude $A_s$ of an echo
sampling time intervall $t_{si}$
0
20
40
60
80
time /sample

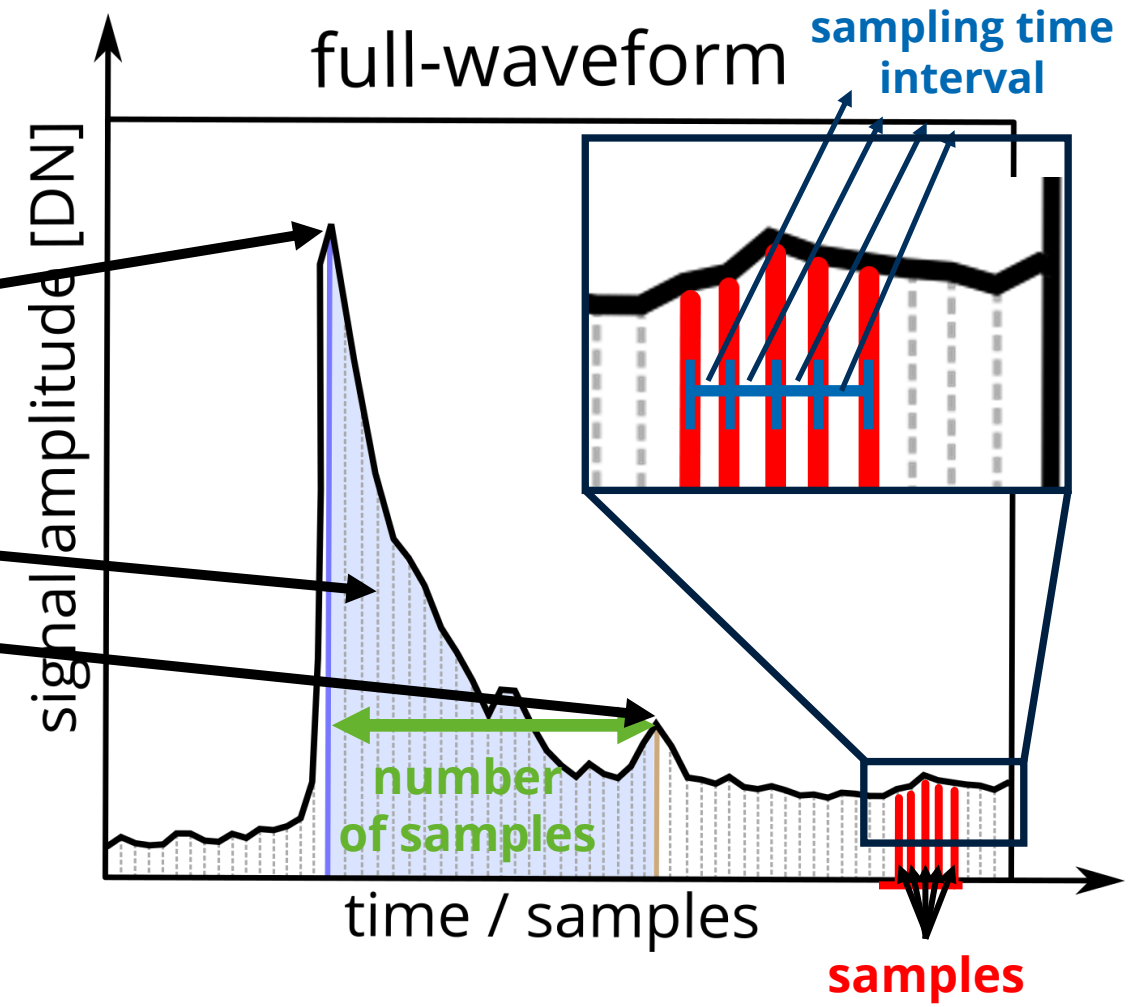

stacked full-waveform
Signal Amplitude [DN]
water surface
water bottom
Samples


1 : 5,000,000
DK
DE
NL
1 : 500,000
Sylt
Föhr
Amrum
1 : 75,000
0
1
2 km
6065000
455000
height coordinate [m]
-2.54
-2.77
-3.00
-3.24
-3.47
-3.70
-3.94
-4.17
-4.40
550m
OWP
sigFWFS
volFWFS

# Measurement principle - airborne laser bathymetry (ALB)

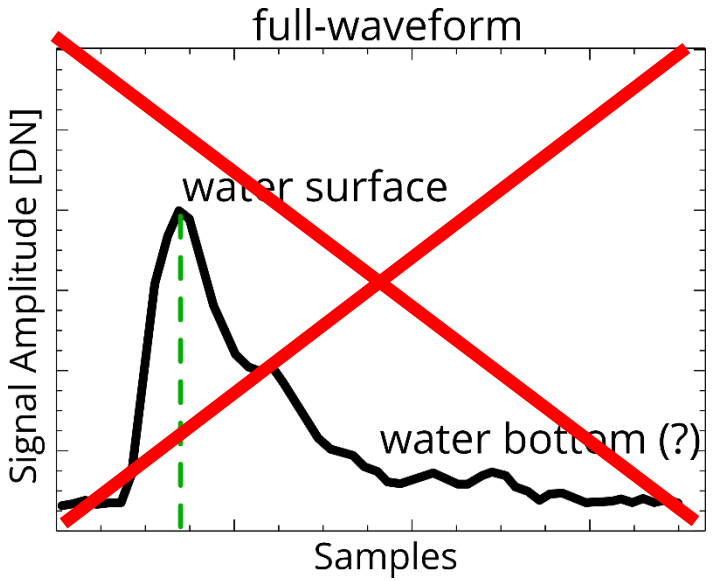
- time-of-flight principle $$D = c \cdot \frac{t_{rt}}{2}$$

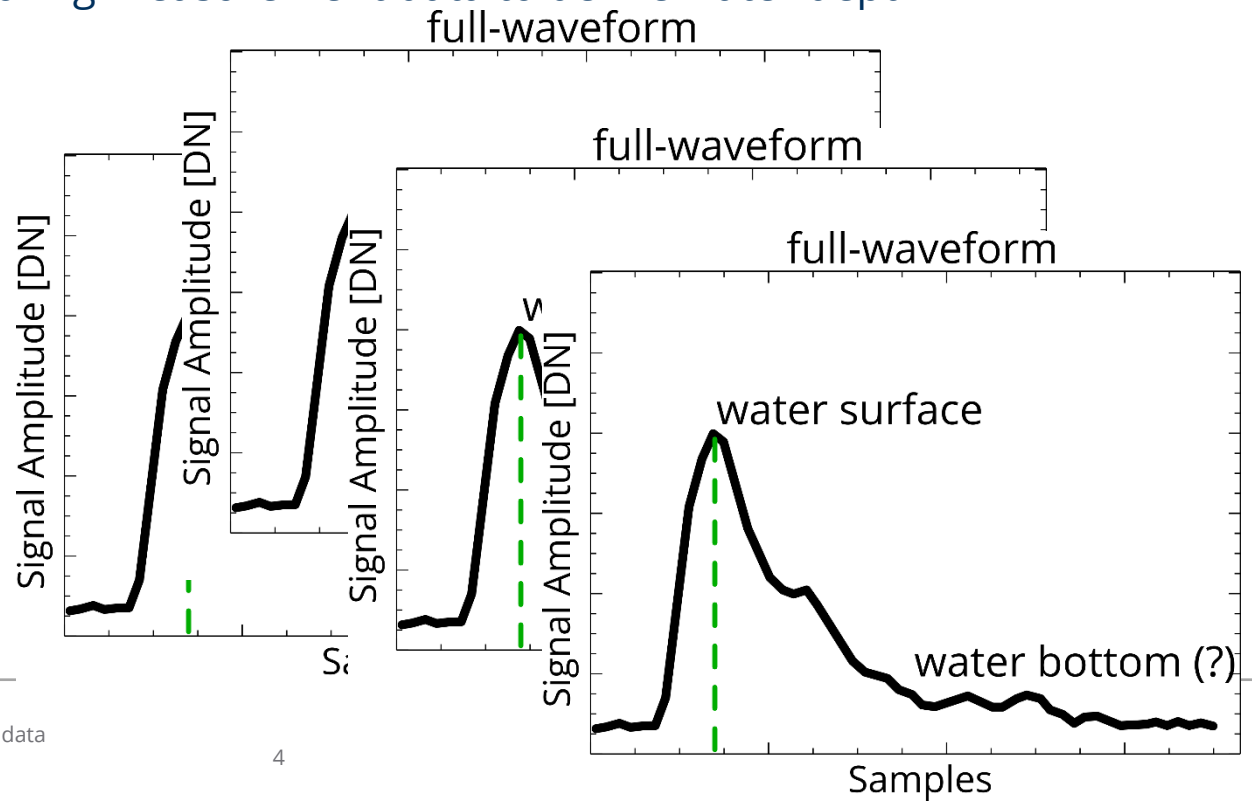
- usage of green laser pulse (532nm)
- full-waveform = Recording and digitizing of the interactions of a laser pulse with:
  - water surface
  - water column
  - water bottom
- full-waveform consists of samples with constant sampling time intervall



# Advanced methods for determining water bottom points

- **basic principle:**
  - assumption: closely neighboring measurement data have very similar characteristics in terms of water depth (with steady water bottoms)
  - no isolated evaluation of the measurement data
  - combined evaluation of spatially closely neighboring measurement data to derive water depth information



PFG (2021) 89:139–158
https://doi.org/10.1007/s41064-021-00147-y

ORIGINAL ARTICLE

# Potential of a Non-linear Full-Waveform Stacking Technique in Airborne LiDAR Bathymetry

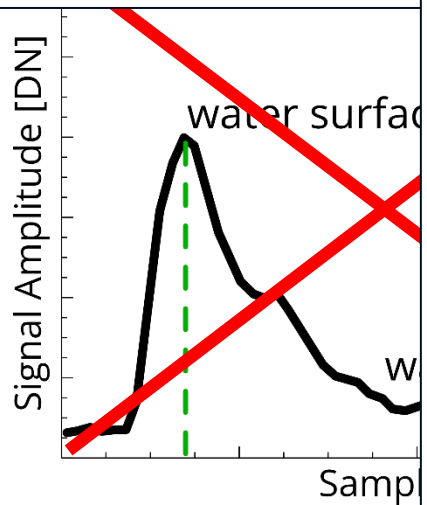
## Demonstration of Full-Waveform Stacking Techniques on Data from the Elbe River

David Mader[1] · Katja Richter[1] · Patrick Westfeld[2] · Hans-Gerd Maas[1]

Received: 29 December 2020 / Accepted:


cs in terms of water

water depth




ISPRS Journal of Photogrammetry and Remote Sensing 204 (2023) 145–162

Contents lists available at ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

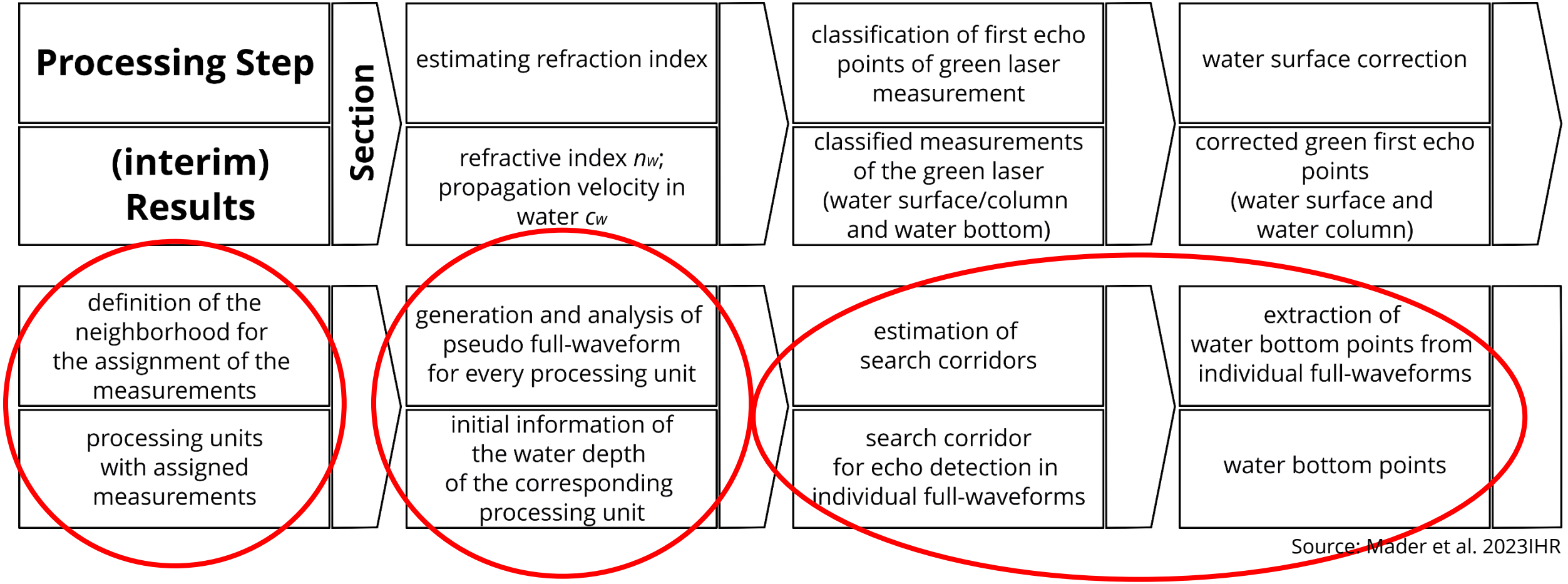
journal homepage: www.elsevier.com/locate/isprsjprs

## Volumetric nonlinear ortho full-waveform stacking in airborne LiDAR bathymetry for reliable water bottom point detection in shallow waters

D. Mader [a,*], K. Richter [a], P. Westfeld [b], H.-G. Maas [a]

[a] Institute of Photogrammetry and Remote Sensing, Dresden University of Technology, Helmholtzstraße 10, 01069 Dresden, Germany
[b] Federal Maritime and Hydrographic Agency of Germany (BSH), Neptunallee 5, 18057 Rostock, Germany

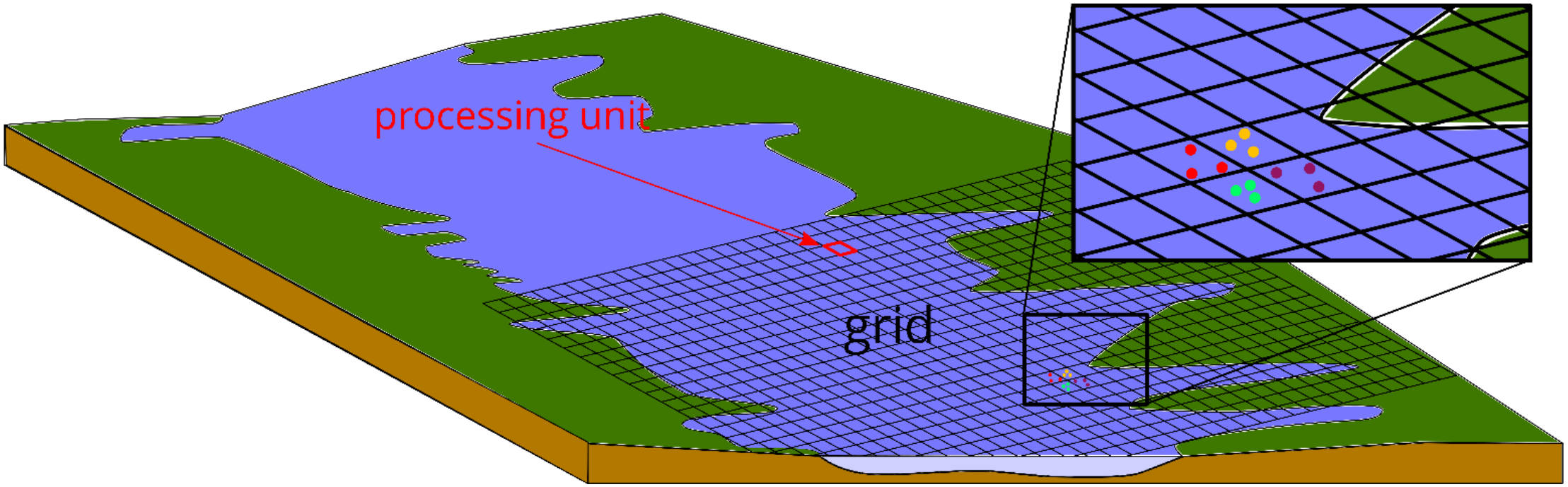
# Advanced methods – full-waveform stacking




Source: Mader et al. 2023IHR

# Advanced methods – signal-based fwf stacking (1) (sigFWFS)

- definition of neighborhood is based on position of first echo point
- partioning of  survey data in a regular grid
- combined processing of all survey data within a grid cell




Source: Mader et al. 2023IHR

PFG (2021) 89:139–158
https://doi.org/10.1007/s41064-021-00147-y

ORIGINAL ARTICLE

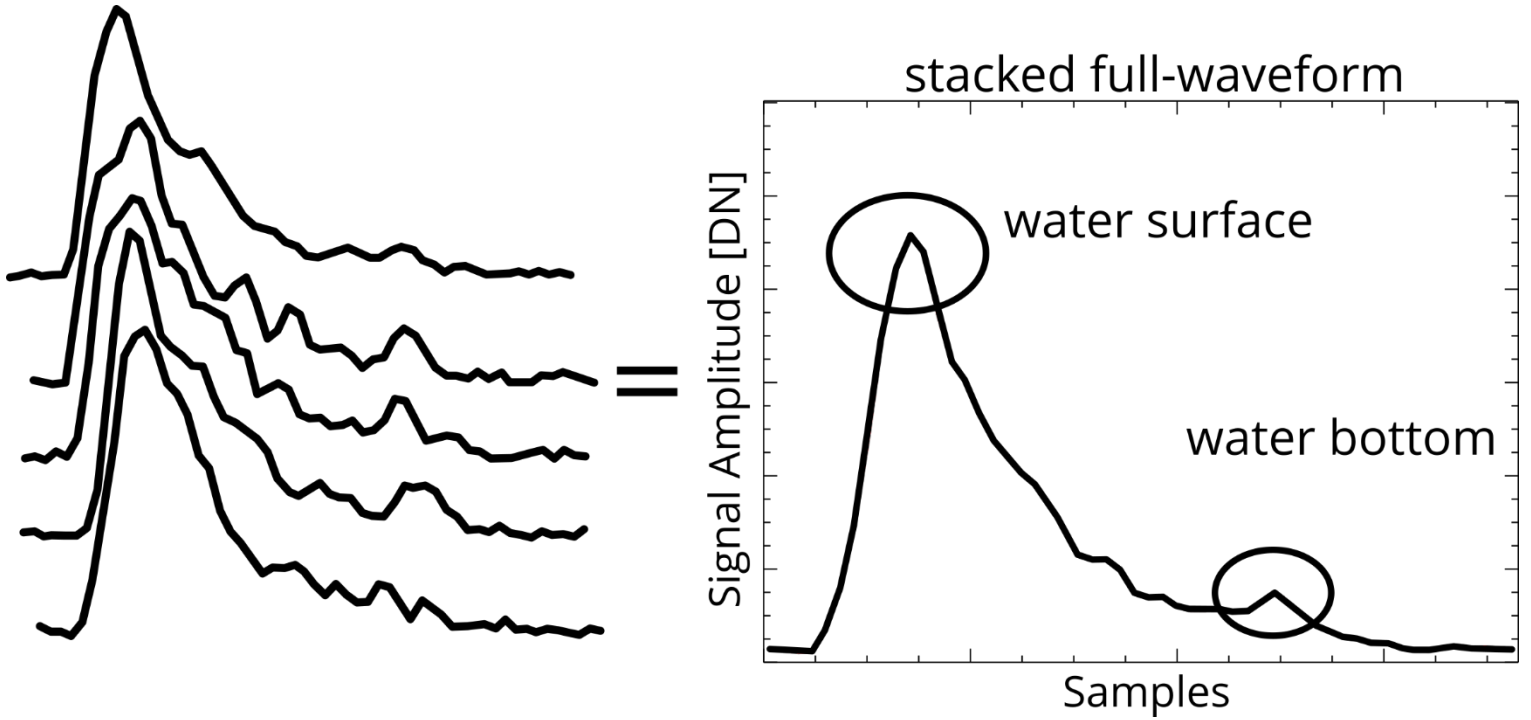
**Potential of a Non-linear Full-Waveform Stacking Technique in Airborne LiDAR Bathymetry**

Demonstration of Full-Waveform Stacking Techniques on Data from the Elbe River

David Mader[1] · Katja Richter[1] · Patrick Westfeld[2] · Hans-Gerd Maas[1]

# Advanced methods – signal-based fwf stacking (2) (sigFWFS)

- alignment of full-waveforms
- accumulation of individual full-waveform to stacked full-waveform
- stacked full-waveform has an improved signal-to-noise ratio




PFG (2021) 89:139–158
https://doi.org/10.1007/s41064-021-00147-y

ORIGINAL ARTICLE

**Potential of a Non-linear Full-Waveform Stacking Technique in Airborne LiDAR Bathymetry**

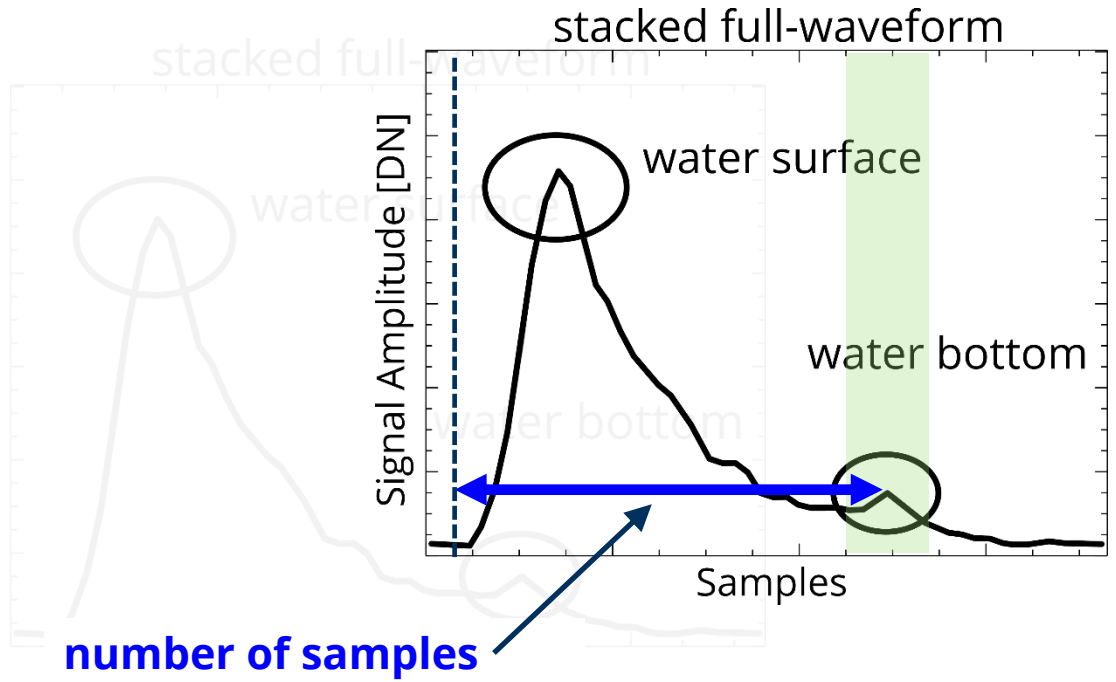
**Demonstration of Full-Waveform Stacking Techniques on Data from the Elbe River**

David Mader[1] · Katja Richter[1] · Patrick Westfeld[2] · Hans-Gerd Maas[1]

# Advanced methods – signal-based fwf stacking (2) (sigFWFS)

- alignment of full-waveforms
- accumulation of individual full-waveform to stacked full-waveform
- stacked full-waveform has an improved signal-to-noise ratio






PFG (2021) 89:139–158
https://doi.org/10.1007/s41064-021-00147-y

ORIGINAL ARTICLE

**Potential of a Non-linear Full-Waveform Stacking Technique in Airborne LiDAR Bathymetry**

**Demonstration of Full-Waveform Stacking Techniques on Data from the Elbe River**

David Mader[1] · Katja Richter[1] · Patrick Westfeld[2] · Hans-Gerd Maas[1]

# Advanced methods – signal-based fwf stacking (2) (sigFWFS)

- alignment of full-waveforms
- accumulation of individual full-waveform to stacked full-waveform
- stacked full-waveform has an improved signal-to-noise ratio

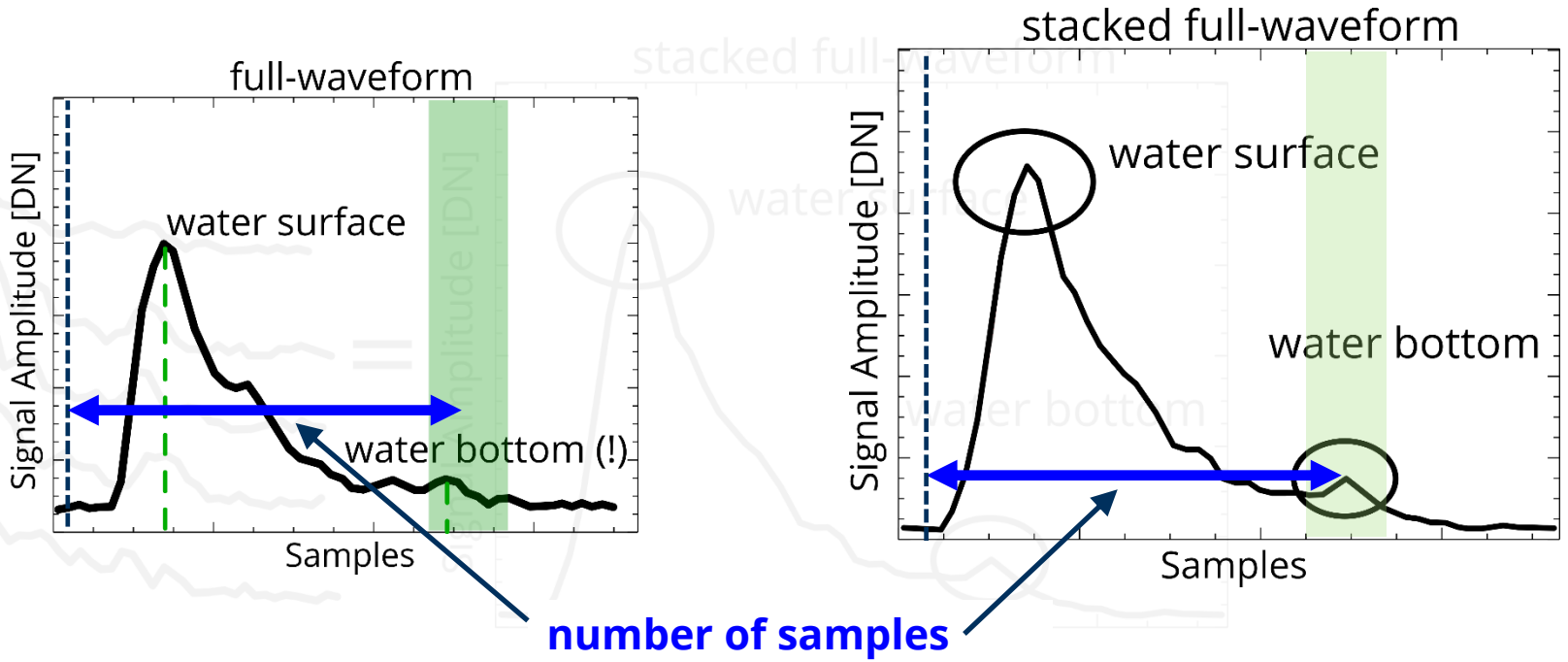
PFG (2021) 89:139–158
https://doi.org/10.1007/s41064-021-00147-y

ORIGINAL ARTICLE

**Potential of a Non-linear Full-Waveform Stacking Technique in Airborne LiDAR Bathymetry**

**Demonstration of Full-Waveform Stacking Techniques on Data from the Elbe River**

David Mader[1] · Katja Richter[1] · Patrick Westfeld[2] · Hans-Gerd Maas[1]



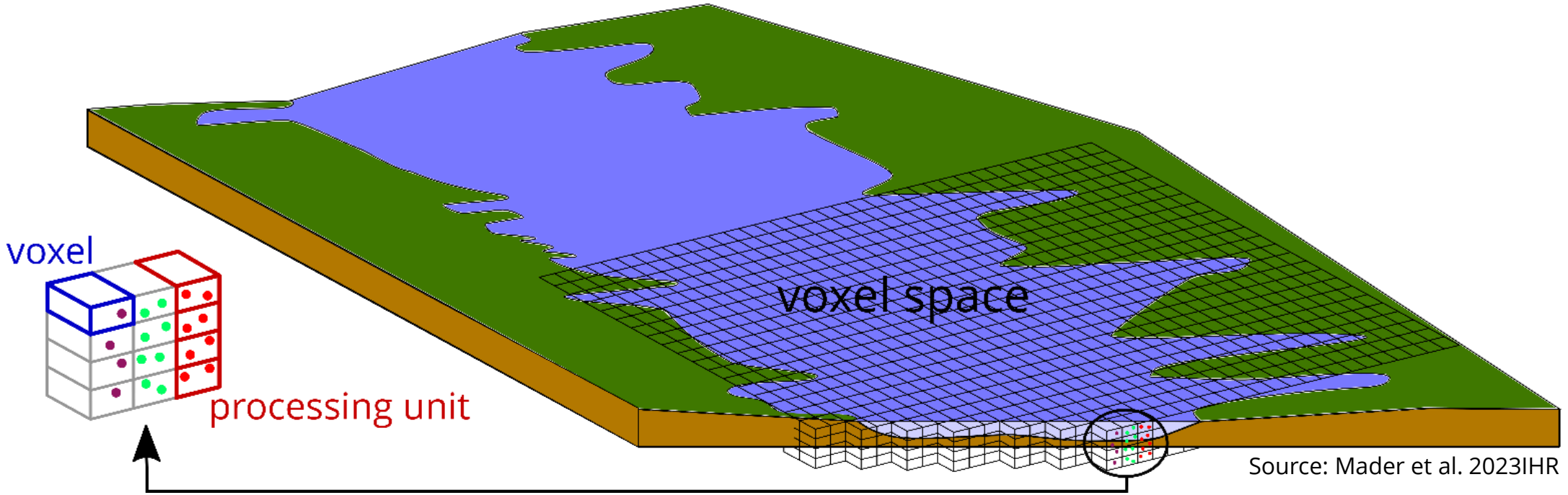
# Advanced methods – volumetric fwf stacking (1) (volFWFS)

Contents lists available at ScienceDirect
ISPRS Journal of Photogrammetry and Remote Sensing
journal homepage: www.elsevier.com/locate/isprsjprs

Volumetric nonlinear ortho full-waveform stacking in airborne LiDAR bathymetry for reliable water bottom point detection in shallow waters

D. Mader [a,*], K. Richter [a], P. Westfeld [b], H.-G. Maas [a]

- integration of all full-waveform information into the voxel space (mapping of amplitudes)
- close neighborhood is guaranteed along the entire water column
- water/voxel column = processing unit




Source: Mader et al. 2023IHR

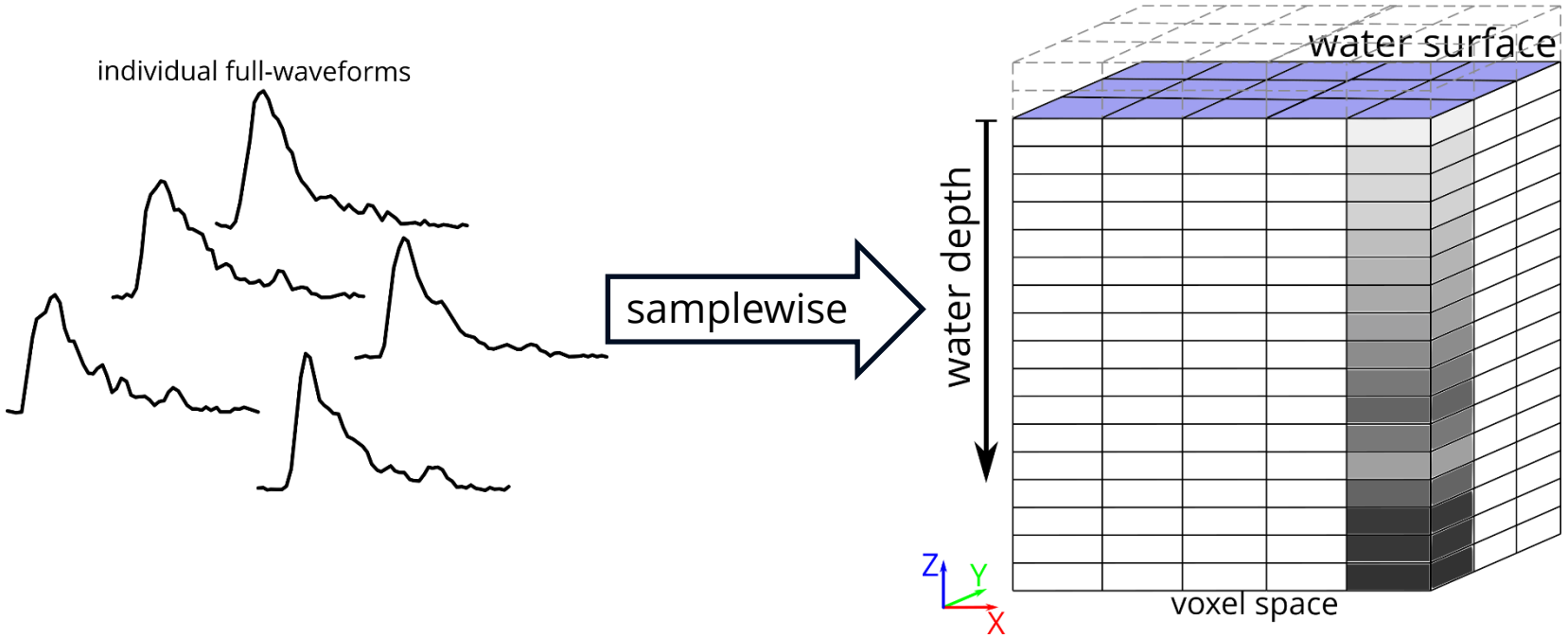
# Advanced methods – volumetric fwf stacking (2) (volFWFS)

Contents lists available at ScienceDirect
ISPRS Journal of Photogrammetry and Remote Sensing
journal homepage: www.elsevier.com/locate/isprsjprs

Volumetric nonlinear ortho full-waveform stacking in airborne LiDAR bathymetry for reliable water bottom point detection in shallow waters

D. Mader [a,*], K. Richter [a], P. Westfeld [b], H.-G. Maas [a]

- mapping of full-waveform sample information into the voxel space
- generation of an ortho full-waveform
- ortho full-waveform has an improved signal-to-noise ratio



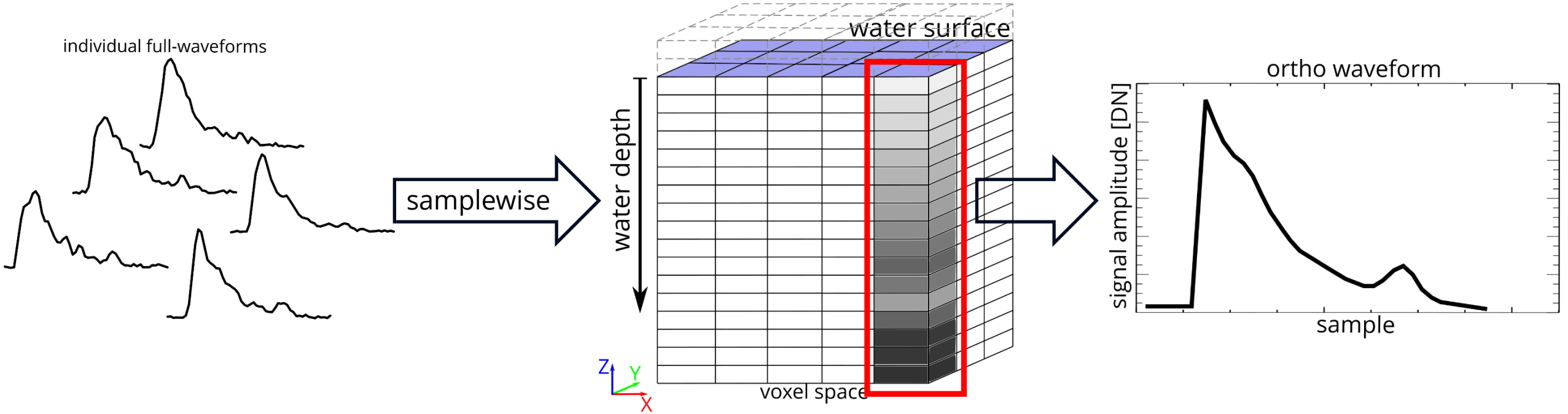
# Advanced methods – volumetric fwf stacking (2) (volFWFS)

Contents lists available at ScienceDirect
ISPRS Journal of Photogrammetry and Remote Sensing
journal homepage: www.elsevier.com/locate/isprsjprs

Volumetric nonlinear ortho full-waveform stacking in airborne LiDAR bathymetry for reliable water bottom point detection in shallow waters

D. Mader [a,*], K. Richter [a], P. Westfeld [b], H.-G. Maas [a]

- mapping of full-waveform sample information into the voxel space
- generation of an ortho full-waveform
- ortho full-waveform has an improved signal-to-noise ratio



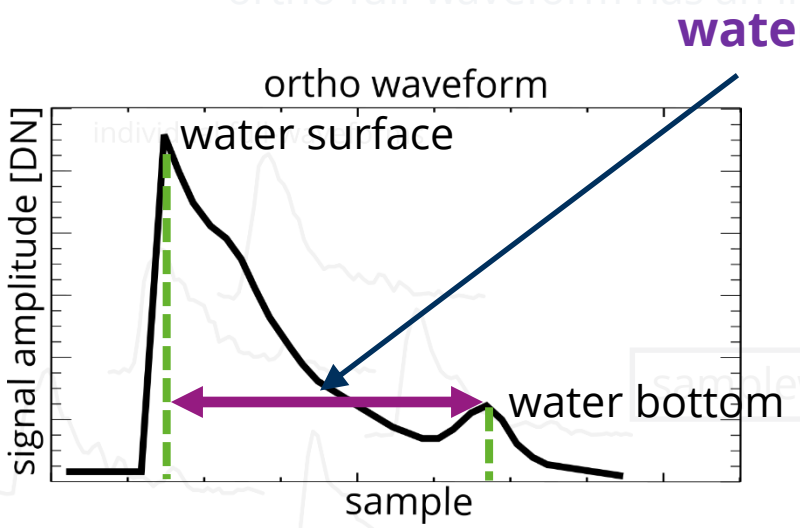
# Advanced methods – volumetric fwf stacking (2) (volFWFS)

Contents lists available at ScienceDirect
ISPRS Journal of Photogrammetry and Remote Sensing
journal homepage: www.elsevier.com/locate/isprsjprs

Volumetric nonlinear ortho full-waveform stacking in airborne LiDAR bathymetry for reliable water bottom point detection in shallow waters

D. Mader [a,*], K. Richter [a], P. Westfeld [b], H.-G. Maas [a]

- mapping of full-waveform sample information into the voxel space
- generation of an ortho full-waveform
- ortho full-waveform has an improved signal-to-noise ratio

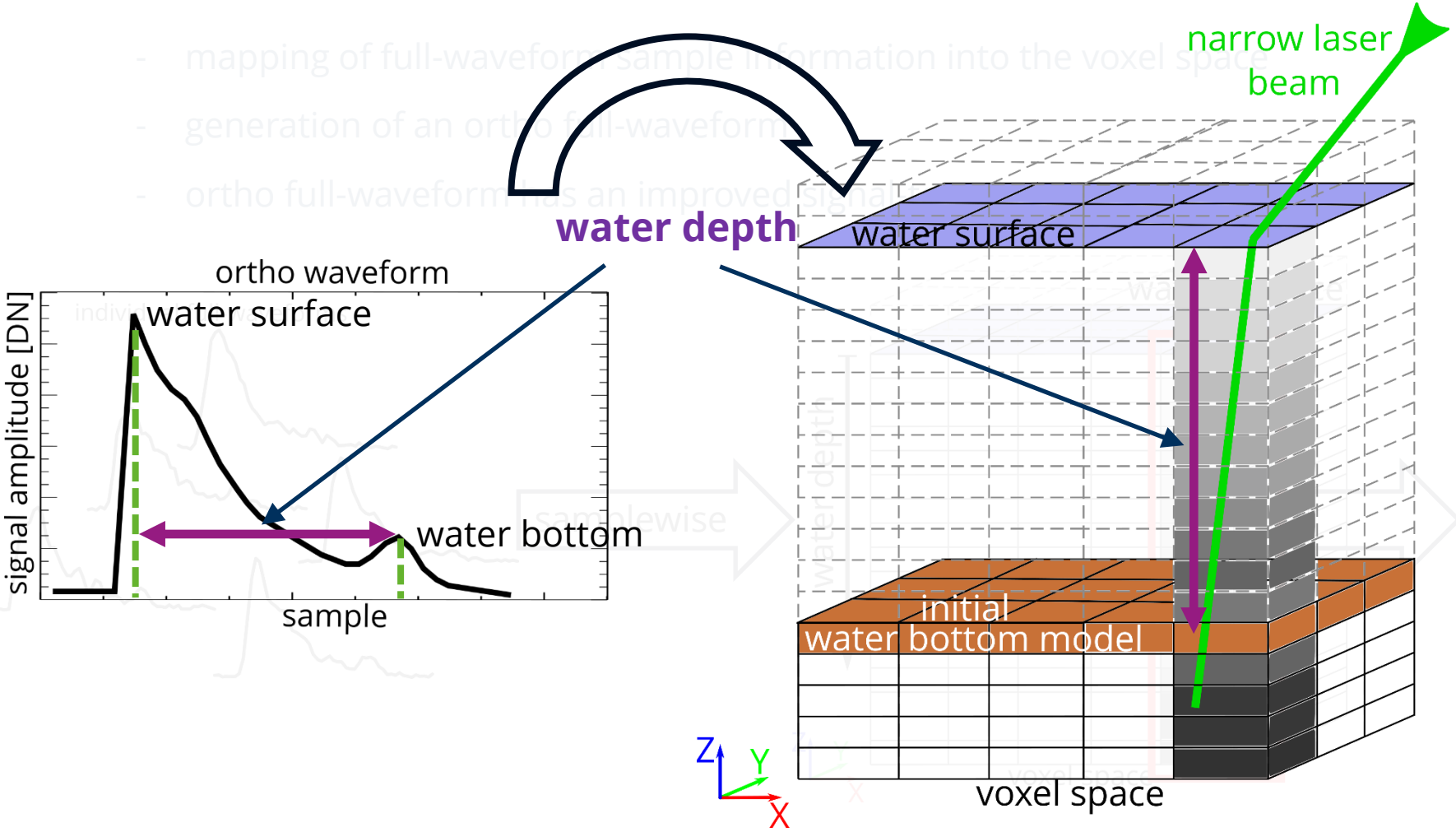


# Advanced methods – volumetric fwf stacking (2) (volFWFS)

Contents lists available at ScienceDirect
ISPRS Journal of Photogrammetry and Remote Sensing
journal homepage: www.elsevier.com/locate/isprsjprs

Volumetric nonlinear ortho full-waveform stacking in airborne LiDAR bathymetry for reliable water bottom point detection in shallow waters

D. Mader [a,*], K. Richter [a], P. Westfeld [b], H.-G. Maas [a]

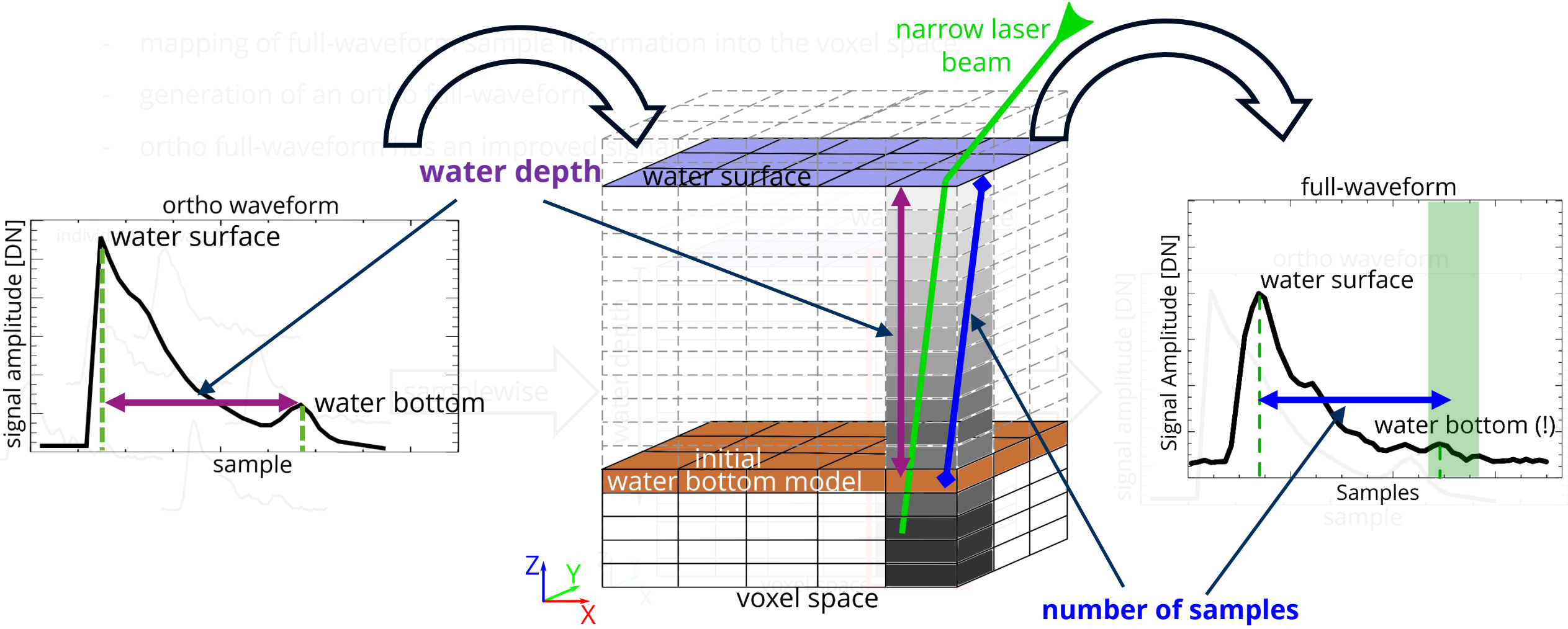


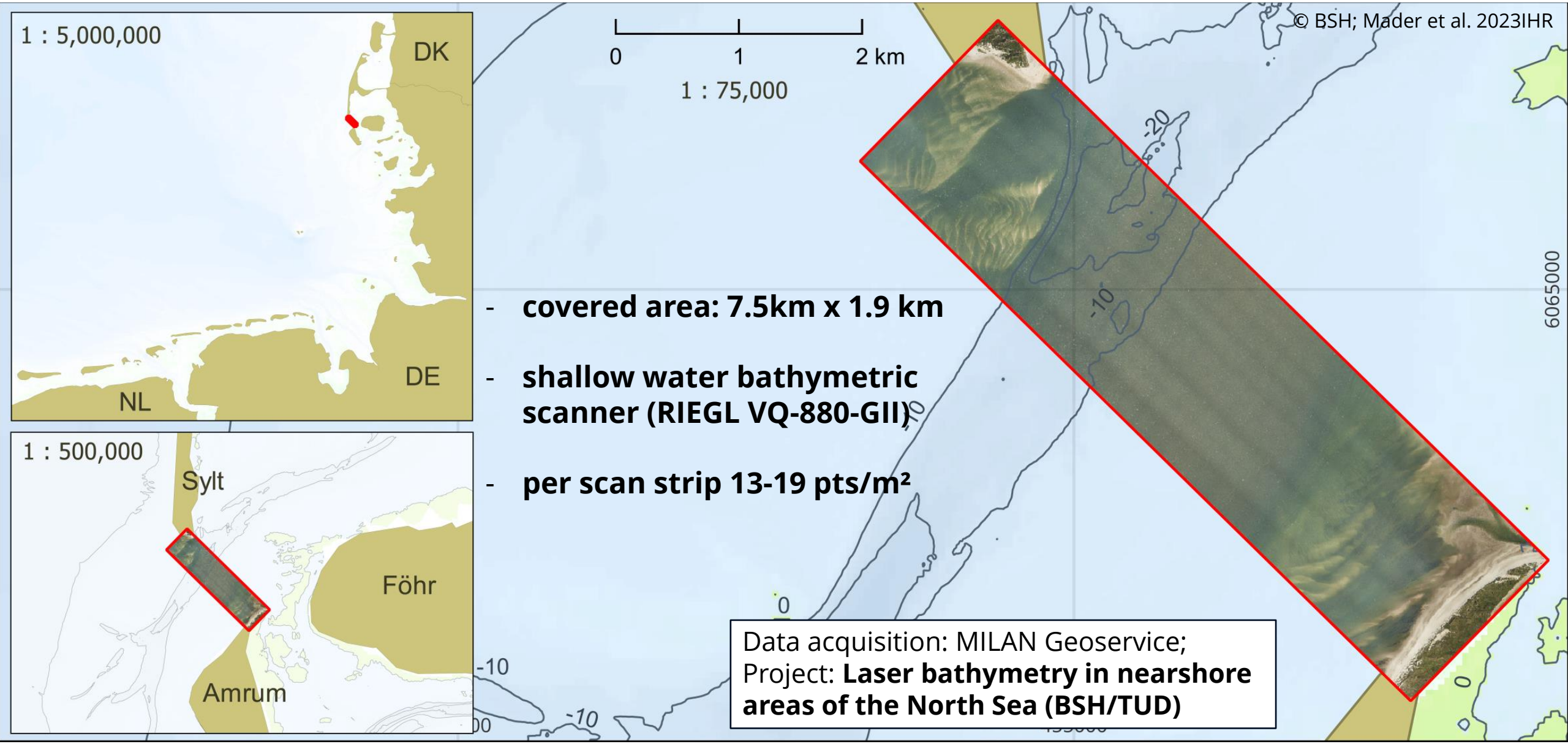
# Advanced methods – volumetric fwf stacking (2) (volFWFS)

Contents lists available at ScienceDirect
ISPRS Journal of Photogrammetry and Remote Sensing
journal homepage: www.elsevier.com/locate/isprsjprs

Volumetric nonlinear ortho full-waveform stacking in airborne LiDAR bathymetry for reliable water bottom point detection in shallow waters

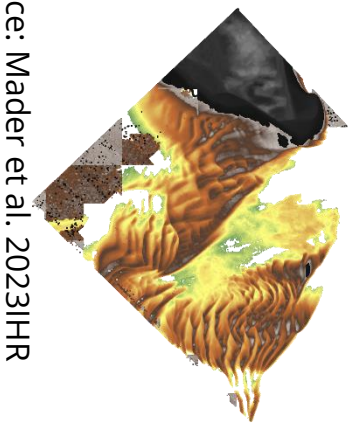
D. Mader [a,*], K. Richter [a], P. Westfeld [b], H.-G. Maas [a]

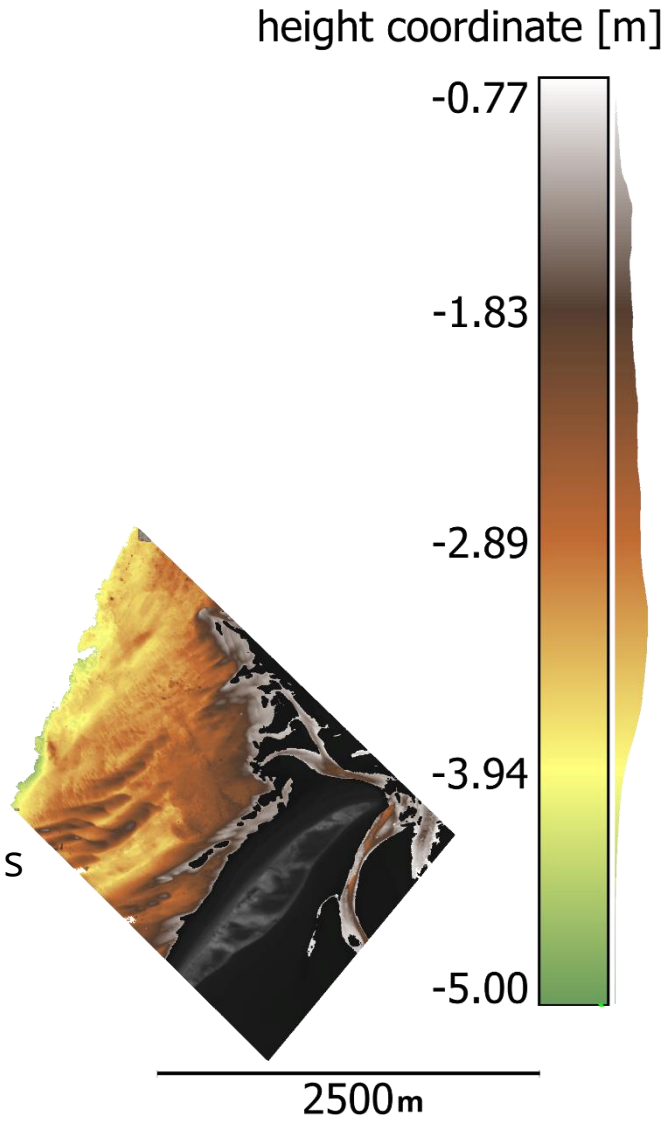



1 : 5,000,000
DK
DE
NL
1 : 500,000
Sylt
Föhr
Amrum
0
1
2 km
1 : 75,000
© BSH; Mader et al. 2023IHR
- covered area: 7.5km x 1.9 km
- shallow water bathymetric scanner (RIEGL VQ-880-GII)
- per scan strip 13-19 pts/m²
Data acquisition: MILAN Geoservice;
Project: Laser bathymetry in nearshore areas of the North Sea (BSH/TUD)
6065000
-20
-10
0

# Laser bathymetry in nearshore areas of the North Sea (BSH/TUD)

Source: Mader et al. 2023IHR

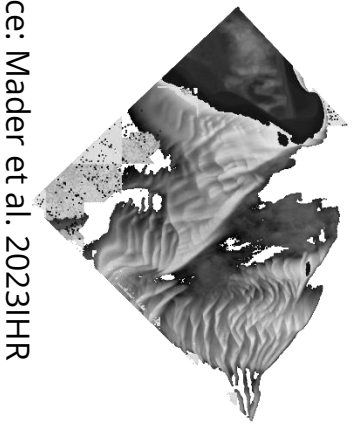


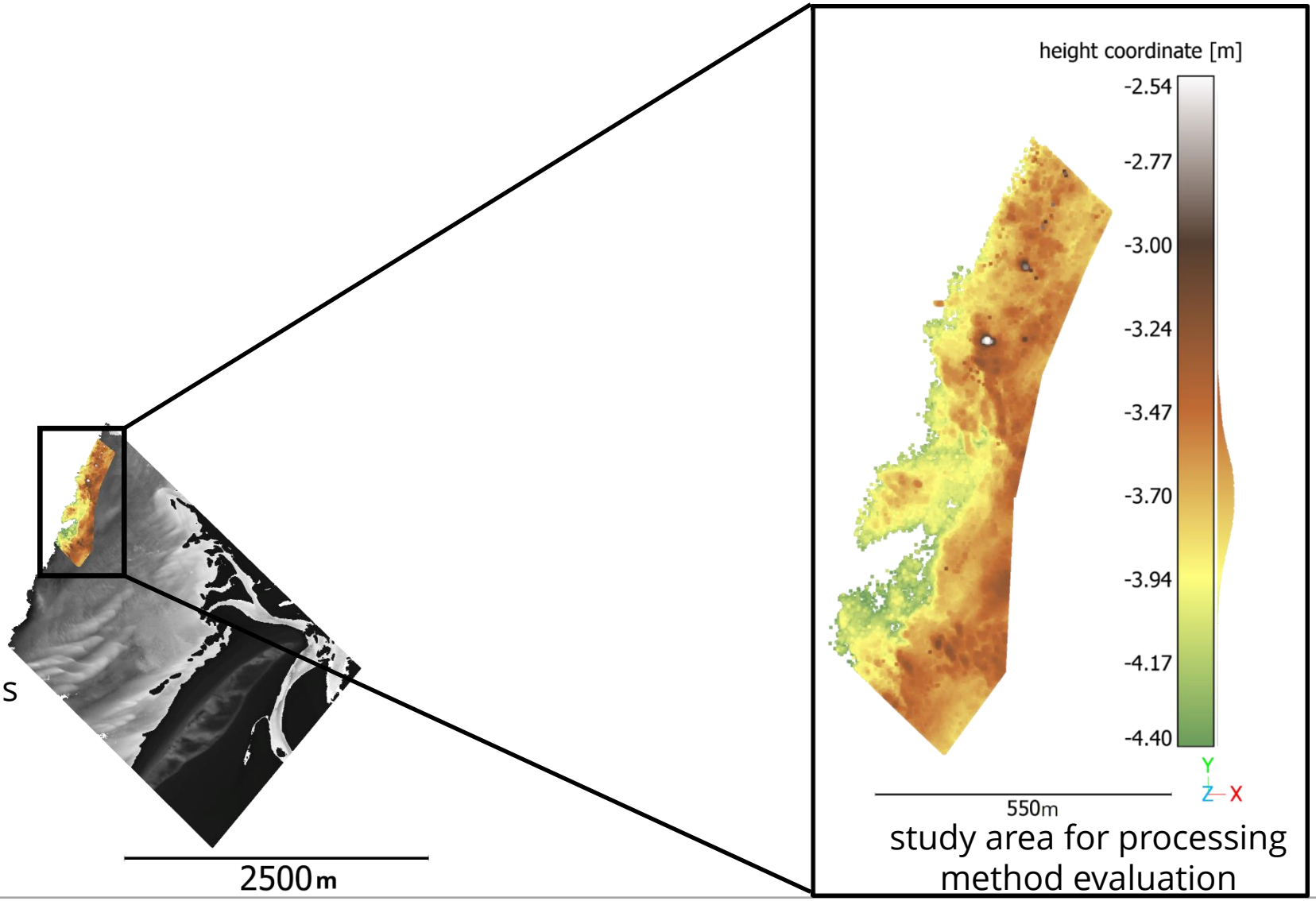



- standard processing methods
- reached water depth 2.87m
- aim: reduction of data gap

# Laser bathymetry in nearshore areas of the North Sea (BSH/TUD)

Source: Mader et al. 2023IHR

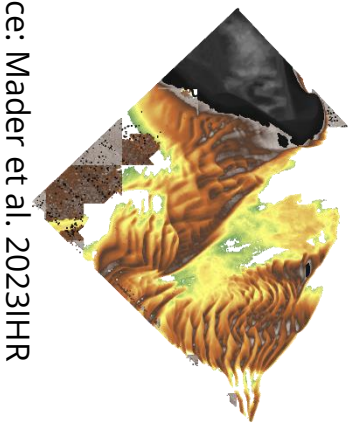


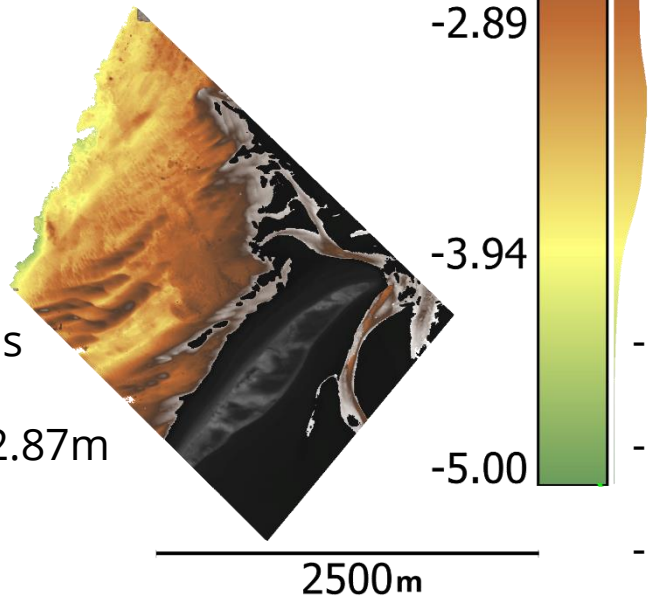



- standard processing methods
- reached water depth 2.87m
- aim: reduction of data gap

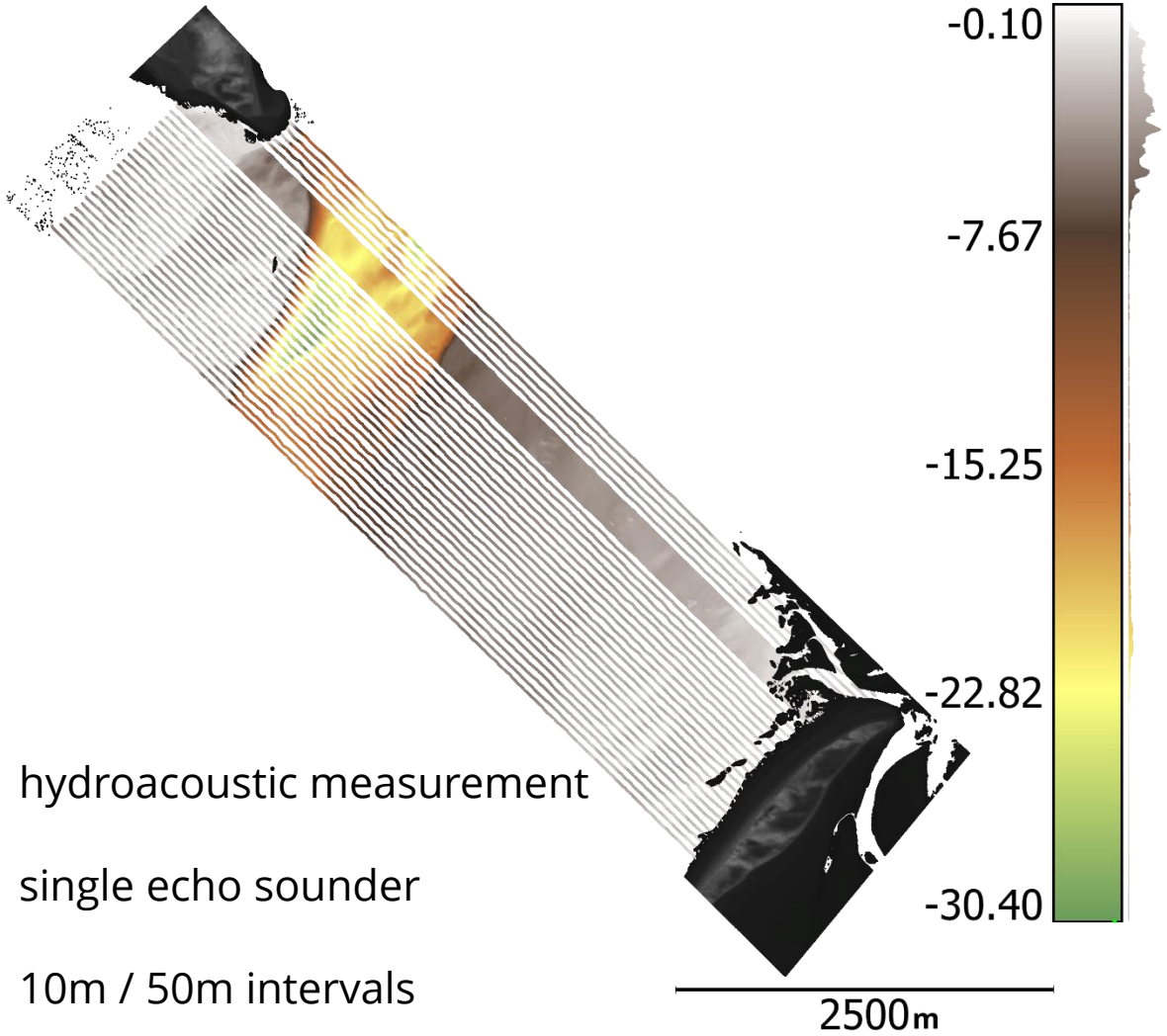
# Laser bathymetry in nearshore areas of the North Sea (BSH/TUD)

Source: Mader et al. 2023IHR





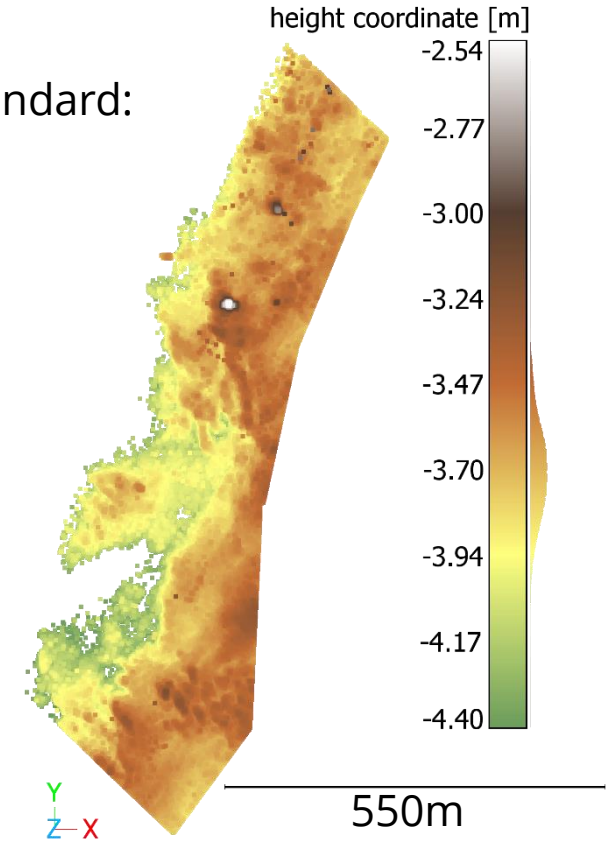

- standard processing methods
- reached water depth about 2.87m
- aim: reduction of data gap



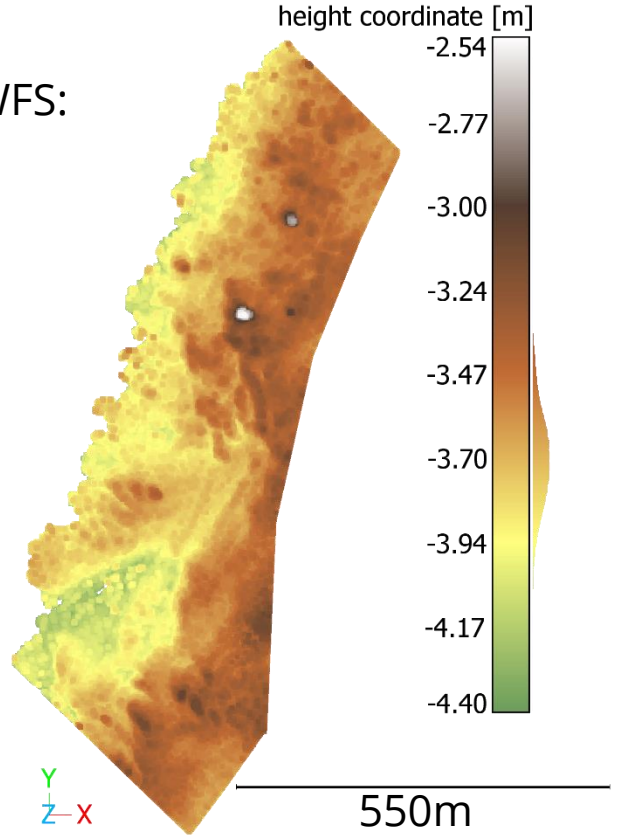

- hydroacoustic measurement
- single echo sounder
- 10m / 50m intervals

# Results – comparison of point cloud with hydroacoustic measurements

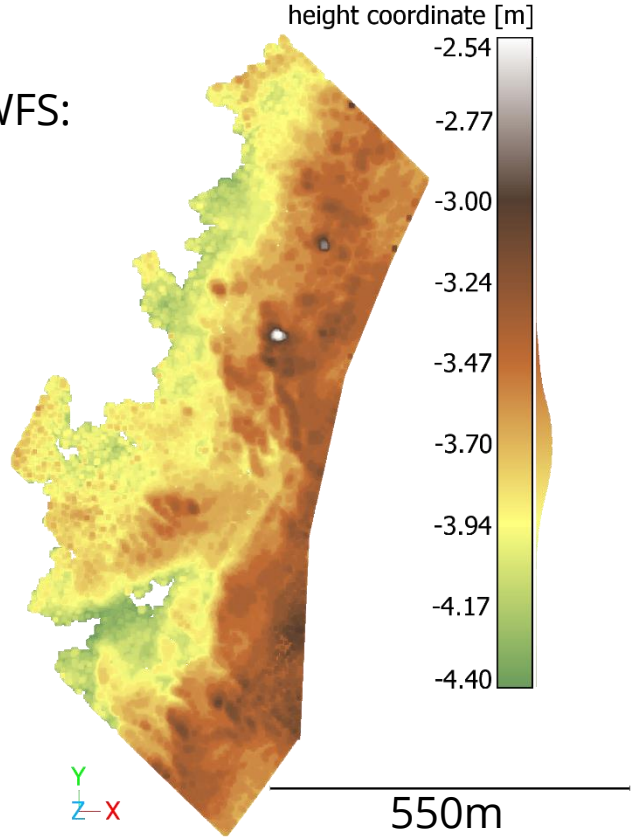
standard:




sigFWFS:



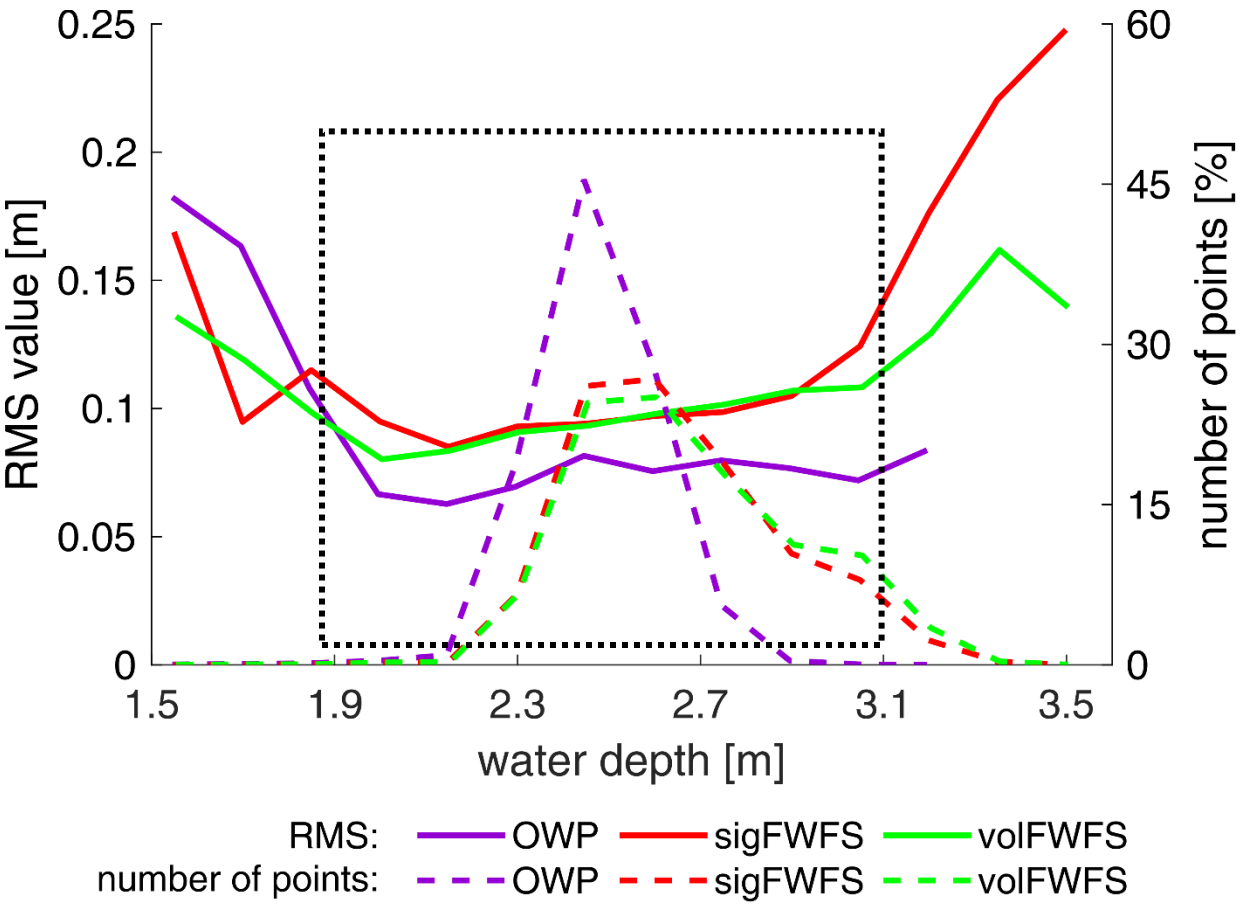

volFWFS:

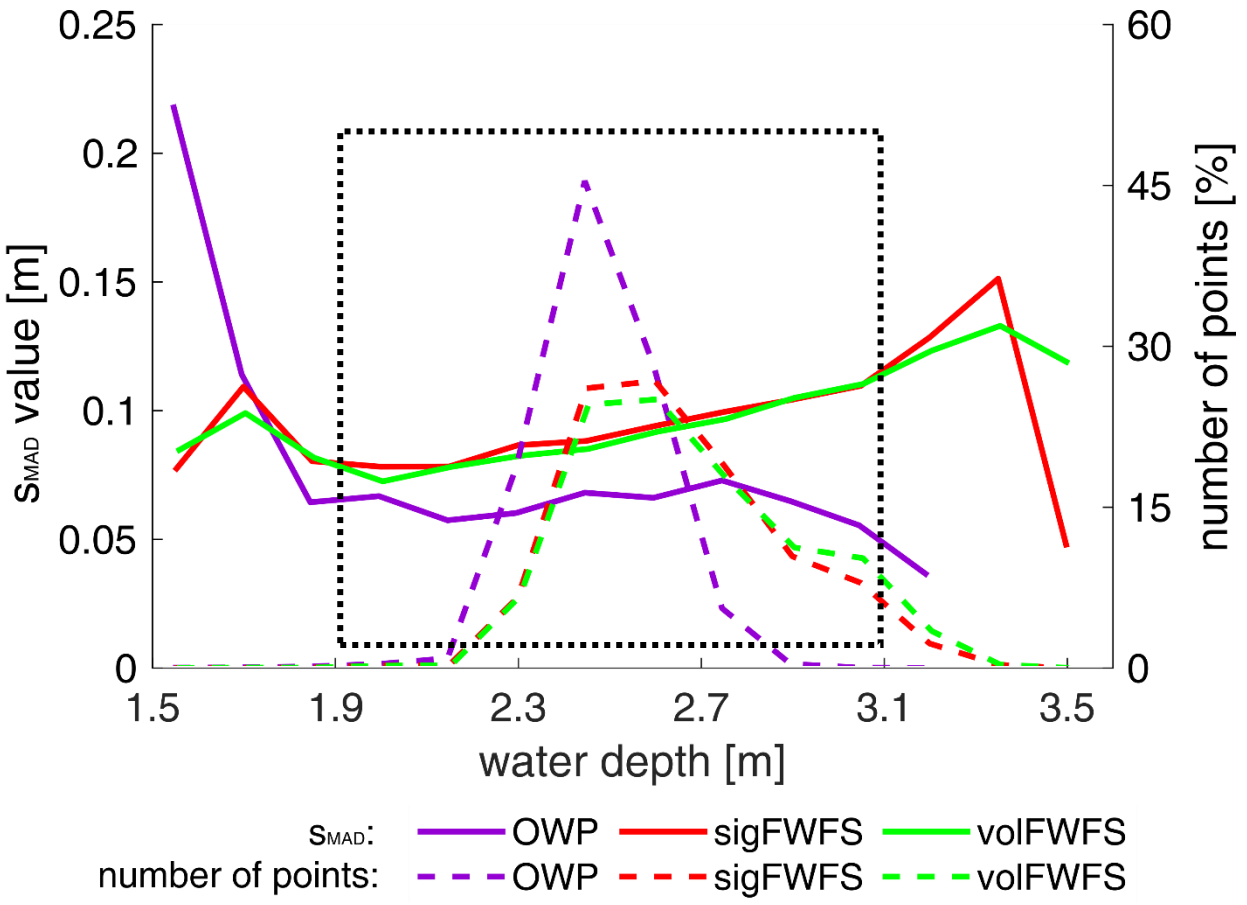



Source: Mader et al. 2023IHR

| | $\overline{\Delta h}$ | $s_{\overline{\Delta h}}$ | $RMS$ | $\sigma_{MAD}$ | $\lvert\overline{\Delta h}\rvert \leq 25\ cm$ TVU special order |
|---|---|---|---|---|---|
| standard | 0.036 m | 0.069 m | 0.078 m | 0.067 m | 99.55 % |
| sigFWFS | 0.00024 m | 0.103 m | 0.103 m | 0.099 m | 98.44 % |
| volFWFS | 0.0099 m | 0.100 m | 0.101 m | 0.096 m | 98.68 % |

# Results – accuracy and reliability as a function of the water depth

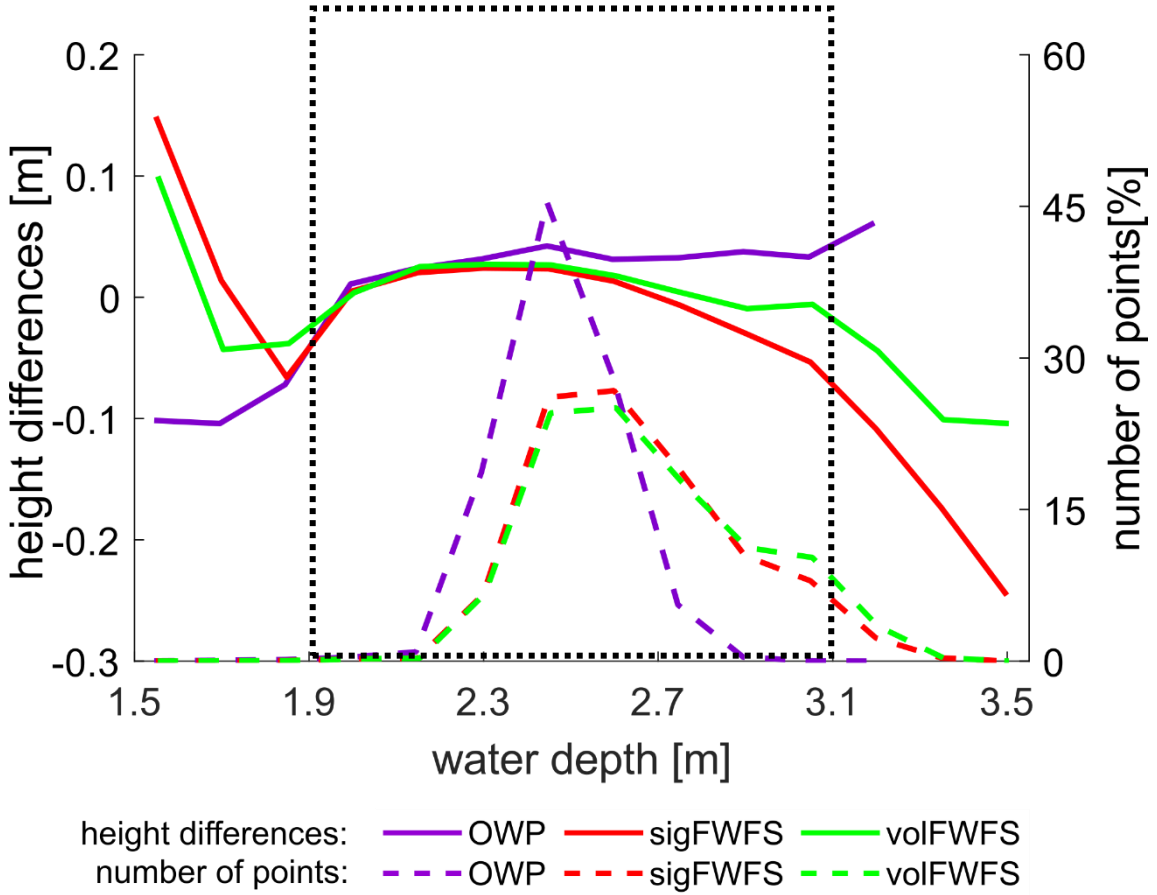


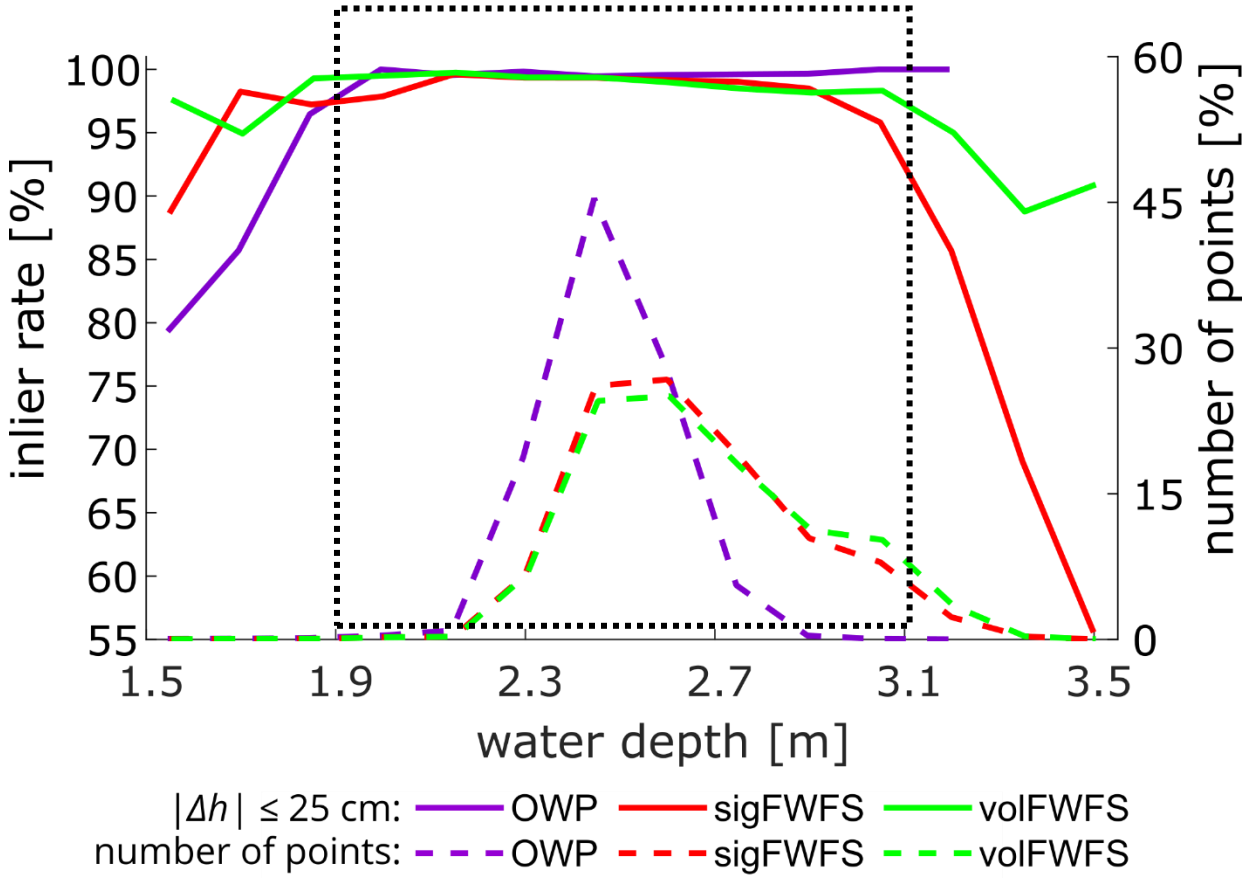




(OWP = standard processing)

Source: Mader et al. 2023IHR

# Results – accuracy and reliability as a function of the water depth

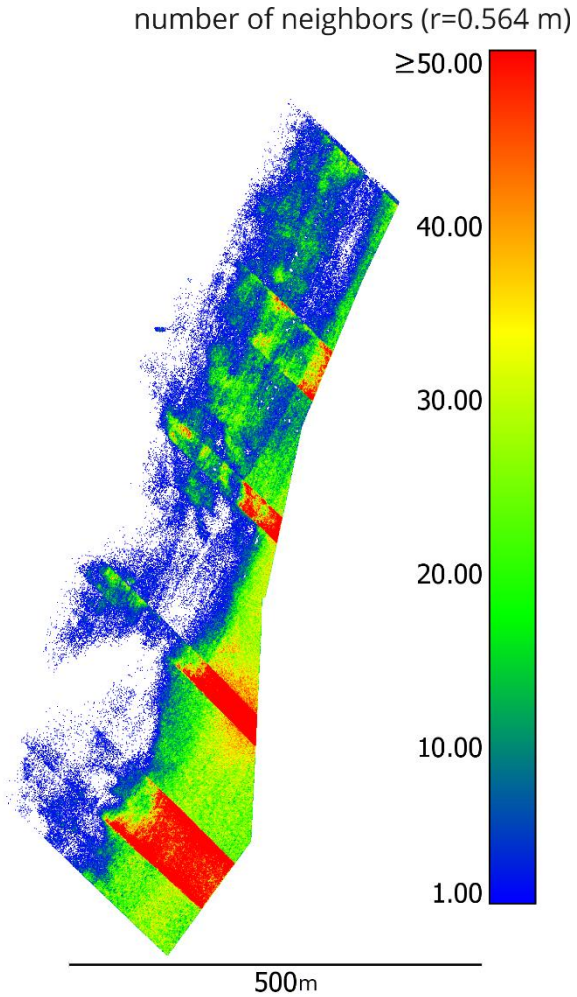


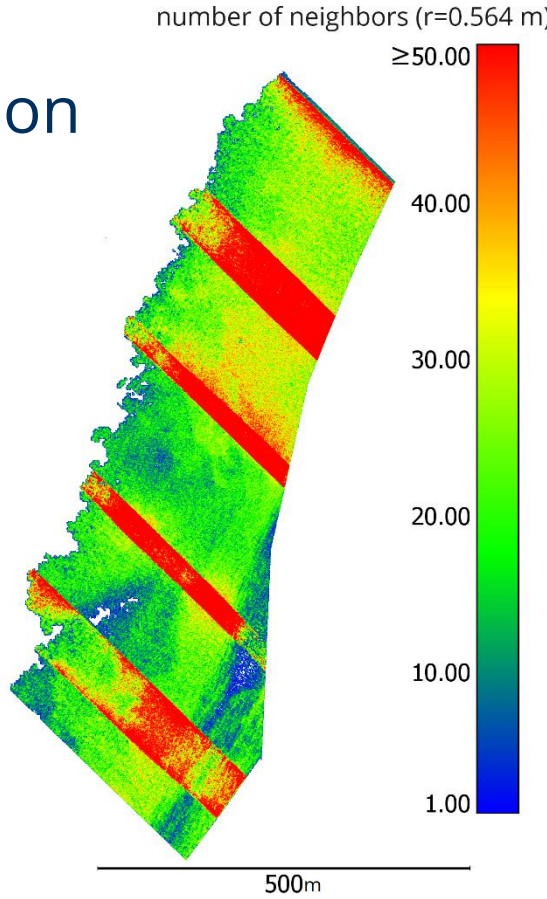

(OWP = standard processing)

Source: Mader et al. 2023IHR

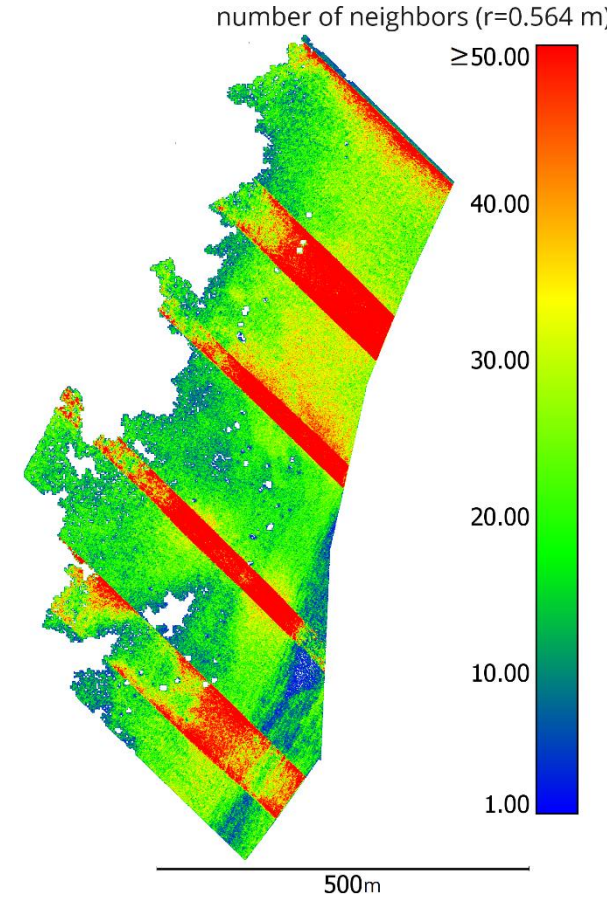
# Results – additional information




standard processing




signal-based fwf-stacking




volumetric fwf-stacking

| | standard | sigFWFS | volFWFS |
|---|---|---|---|
| area comparison | 100 % | 111.4 % | 114.6 % |
| reached water depth | 2.87 m | 3.56m (+24.0%) | 3.62 m (+26.1%) |

(for areas with a point density ≥ 5 points/m²)

Source: Mader et al. 2023IHR

# Publications regarding full-waveform stacking processing methods

**signal-based full-waveform stacking (PFG Journal):**

- Mader, D., Richter, K., Westfeld, P. & Maas, H. (2021). Potential of a Non-linear Full-Waveform Stacking Technique in Airborne LiDAR Bathymetry. *PFG – Journal Of Photogrammetry Remote Sensing And Geoinformation Science, 89*(2), 139–158. **https://doi.org/10.1007/s41064-021-00147-y**

**volumetric full-waveform stacking (ISPRS Journal):**

- Mader, D., Richter, K., Westfeld, P. & Maas, H. (2023). Volumetric nonlinear ortho full-waveform stacking in airborne LiDAR bathymetry for reliable water bottom point detection in shallow waters. *ISPRS Journal Of Photogrammetry And Remote Sensing, 204*, 145–162. **https://doi.org/10.1016/j.isprsjprs.2023.08.014**

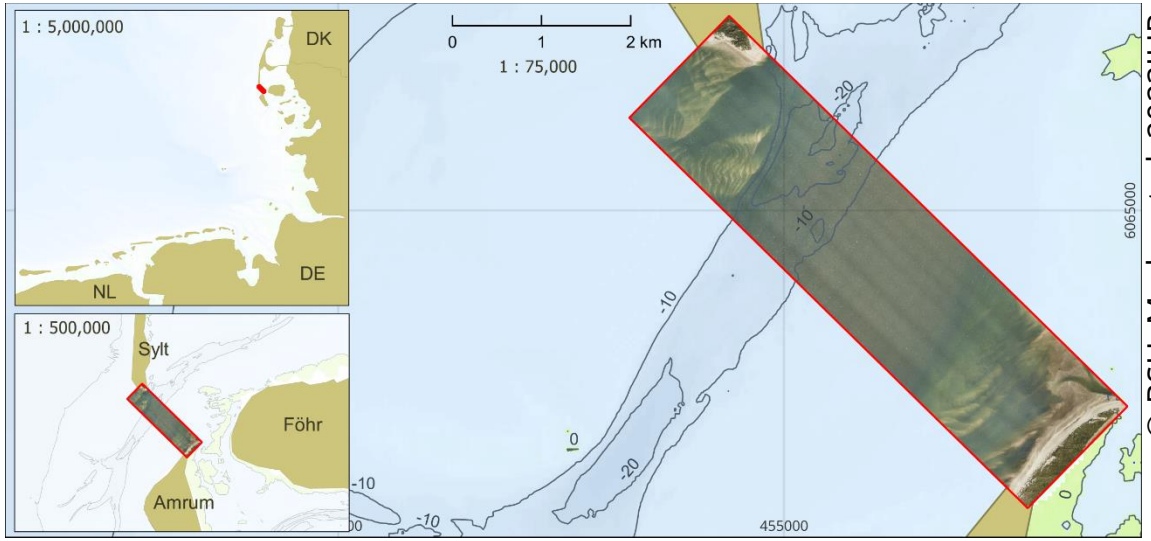
**application to maritime water - North Sea (The International Hydrographic Review - IHR):**

- Mader, D., Richter, K., Westfeld, P., Nistad, J. & Maas, H. (2023). Analysis of the potential of full-waveform stacking techniques applied to coastal airborne LiDAR bathymetry data of the German Wadden Sea National Park. *The International Hydrographic Review, 29*(2), 46–64. **https://doi.org/10.58440/ihr-29-2-a31**

**For more information please contact: david.mader@tu-dresden.de**

# Research Project - Laser bathymetry in nearshore areas of the North Sea

project website (TUD)




© BSH; Mader et al. 2023IHR

project article in the IHR

Dr.-Ing. David Mader
TU Dresden

Dr.-Ing. Katja Richter
TU Dresden

Dr.-Ing. Patrick Westfeld
BSH Rostock

Prof. Dr. habil Hans-Gerd Maas
TU Dresden