Remote Sensing of Near-Surface Vertical Current Shear

Benjamin K. Smeltzer, Simen Å. Ellingsen

EGU2020: Sharing Geoscience Online

Norwegian University of Science and Technology

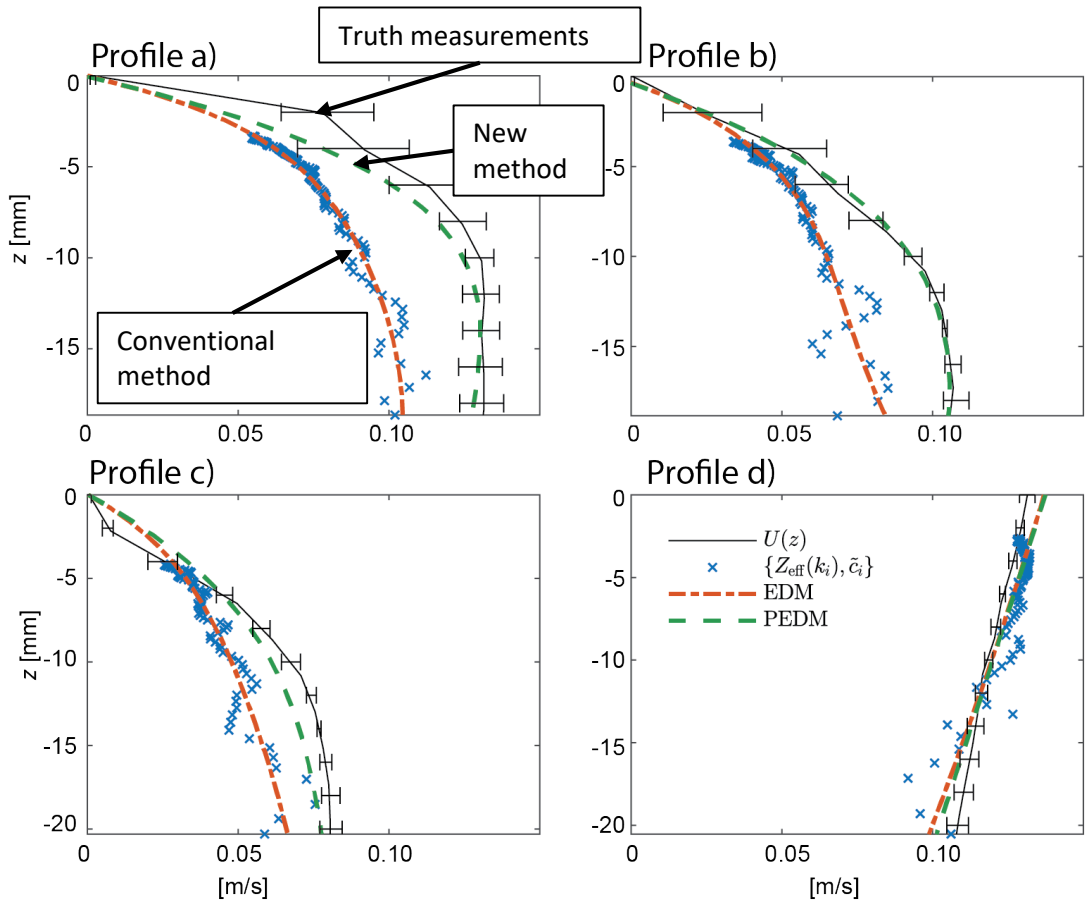
One-Slide Summary

- We have developed a new method for determining the depth profile of near-surface currents from measurements of the wave spectrum. The method, termed the PEDM, is demonstrated to improve the accuracy of reconstructed currents relative to state-of-the-art conventional methods.

- The method is tested and validated in a laboratory where currents with different depth-profiles could be created. In situ particle image velocimetry (PIV) of the flow served as truth measurements.

- The figure to the right shows the results for 4 current profiles as a function of depth (vertical axis).

See the following slides for further details on the work.



Contact: benjamin.smeltzer@ntnu.no

The work presented here is based on the following article:

AGU100 ADVANCING EARTH AND SPACE SCIENCE

JGR Oceans

RESEARCH ARTICLE

10.1029/2019JC015202

Key Points:

- A simple and more accurate method for reconstructing near-surface current profiles from wave spectra is presented

An Improved Method for Determining Near-Surface Currents From Wave Dispersion Measurements

B. K. Smeltzer[1], E. Æsøy[1], A. Ådnøy[1], and S. Å. Ellingsen[1]

[1] Department of Energy and Process Engineering, Norwegian University of Science and Technology, Trondheim, Norway

Motivation

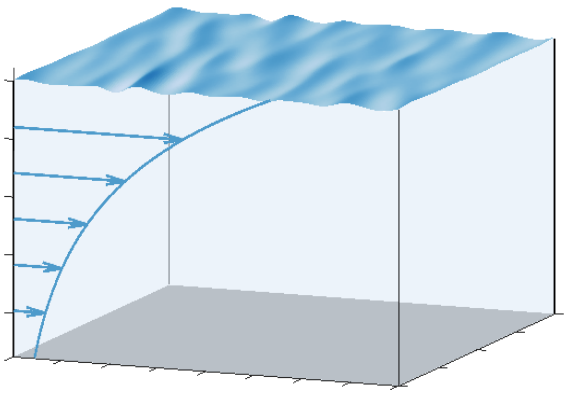
- A depth-varying current affects the speeds of surface waves. Remote sensing involves the inverse: to reconstruct the velocity profile based on observations of wave dispersion.

- Observations indicate significant vertical current shear in the first few meters depth[2,4,6]. In situ point measurements at one depth don't capture the 'full picture.'
  - Near-surface current measurements are important for understanding upper-ocean processes, microplastic & oil slick transport, and more...

- Traditional measurements are difficult near the surface. Conventional techniques, e.g. ADCP, struggle in first few meters depth.

- Determining currents from measurements of the wave spectrum (Inversion methods) is an attractive alternative.

- Typical methods for measuring the directional wave spectrum include X-band radar as well as optical techniques such as drone videos.



Remote sensing: current inversion

Advantages	Challenges
Maps currents over large horizontal area simultaneously	Results depend on wave spectrum
Greatest sensitivity near the surface, a present 'blind spot'	Ill-posed inverse problem: measurement noise is amplified

https://www.sea-hawk.com/products/Sea-Hawk-SHN-X12.aspx

J. Horstmann, et al. *Proc. OCEANS-Aberdeen*, 2017

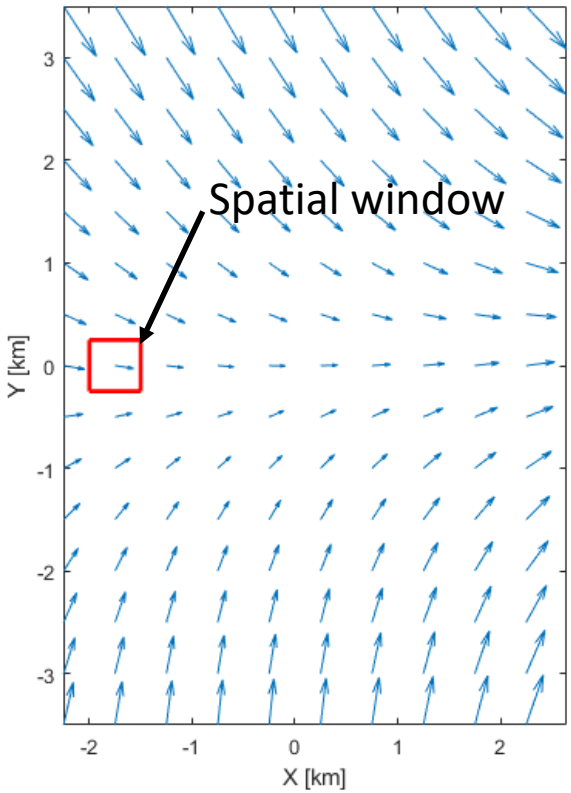
Reconstructing horizontally and depth-varying currents

- Most previous remote sensing work of near-surface currents reconstructs only the horizontal spatial variation of the currents, yielding one current vector per spatial window, a weighted-depth average.

- Our work herein resolves the variation with depth within a single window, analyzing waves over a broad range of wavelengths.

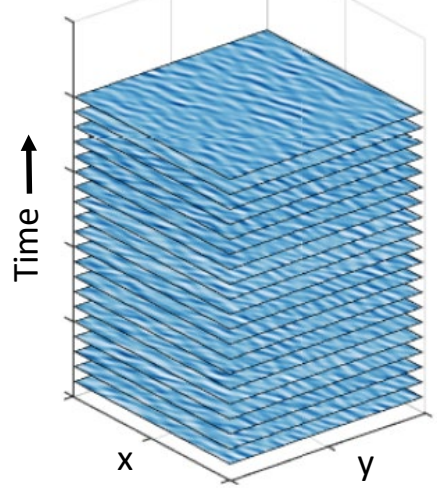
- Ultimately, as both approaches are combined, there is in most cases a tradeoff between horizontal spatial resolution and depth profile range and accuracy.
  - Many wavelengths are required within each window for accurate results. Reconstructing the depth profile requires long wavelengths to resolve greater depths, leading to larger spatial window sizes which limits spatial resolution.

Top View



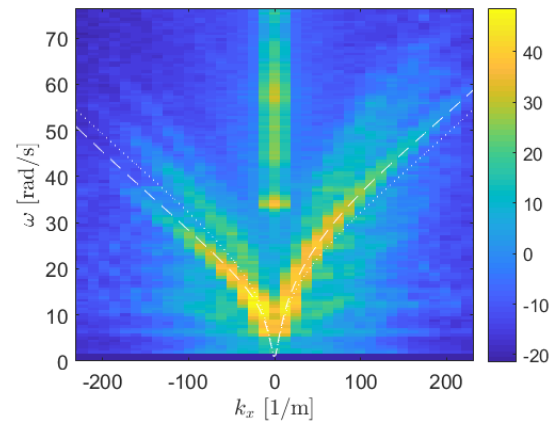
Inversion Method Procedure

1.) Measure the waves in space and time

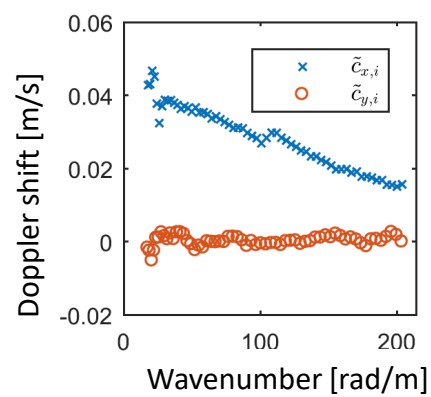


3D FFT

2.) Perform a 3D Fourier transform to convert to wave spectrum ***k***-ω

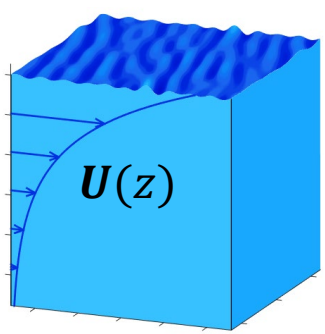


3.) Extract wavelength-dependent Doppler shifts $\tilde{\boldsymbol{c}}(k)$, the current-induced change in the phase velocities



Using an inversion method

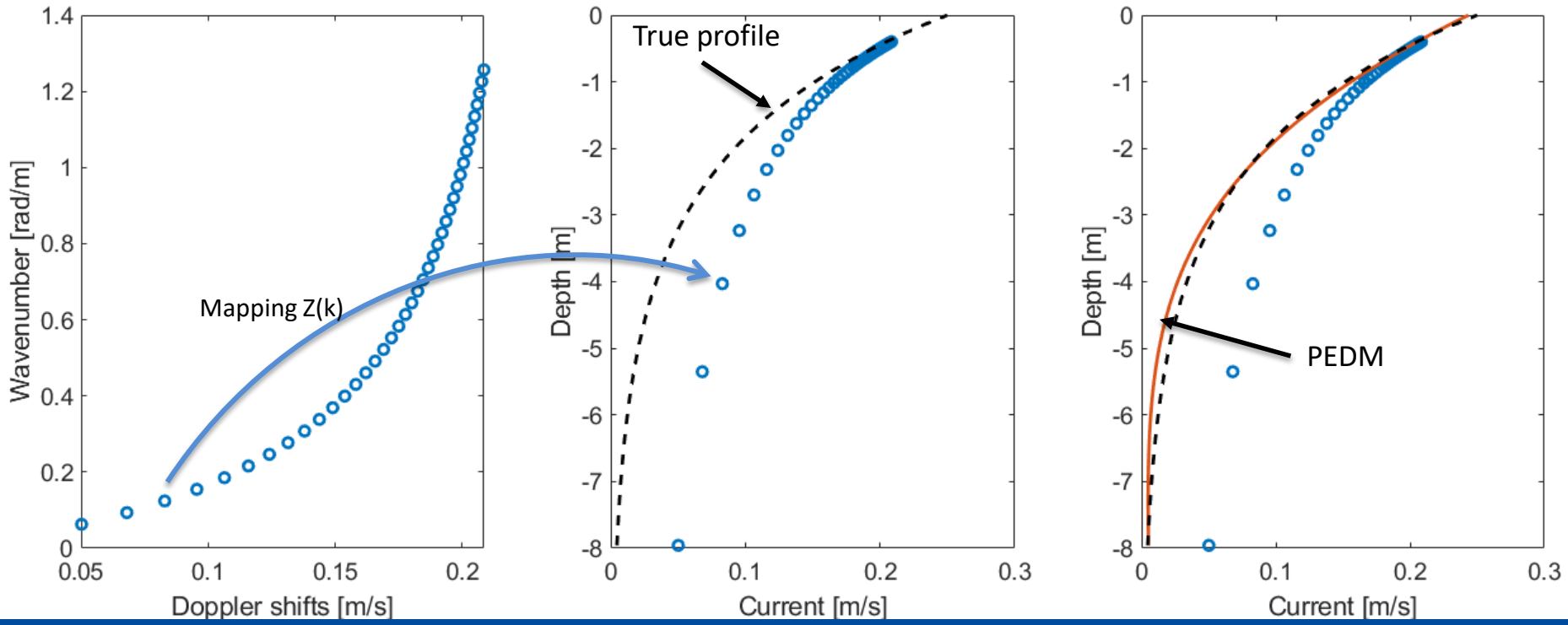
4.) Reconstruct the depth-dependent current ***U***(*z*)



Focus here: step 3 -> 4

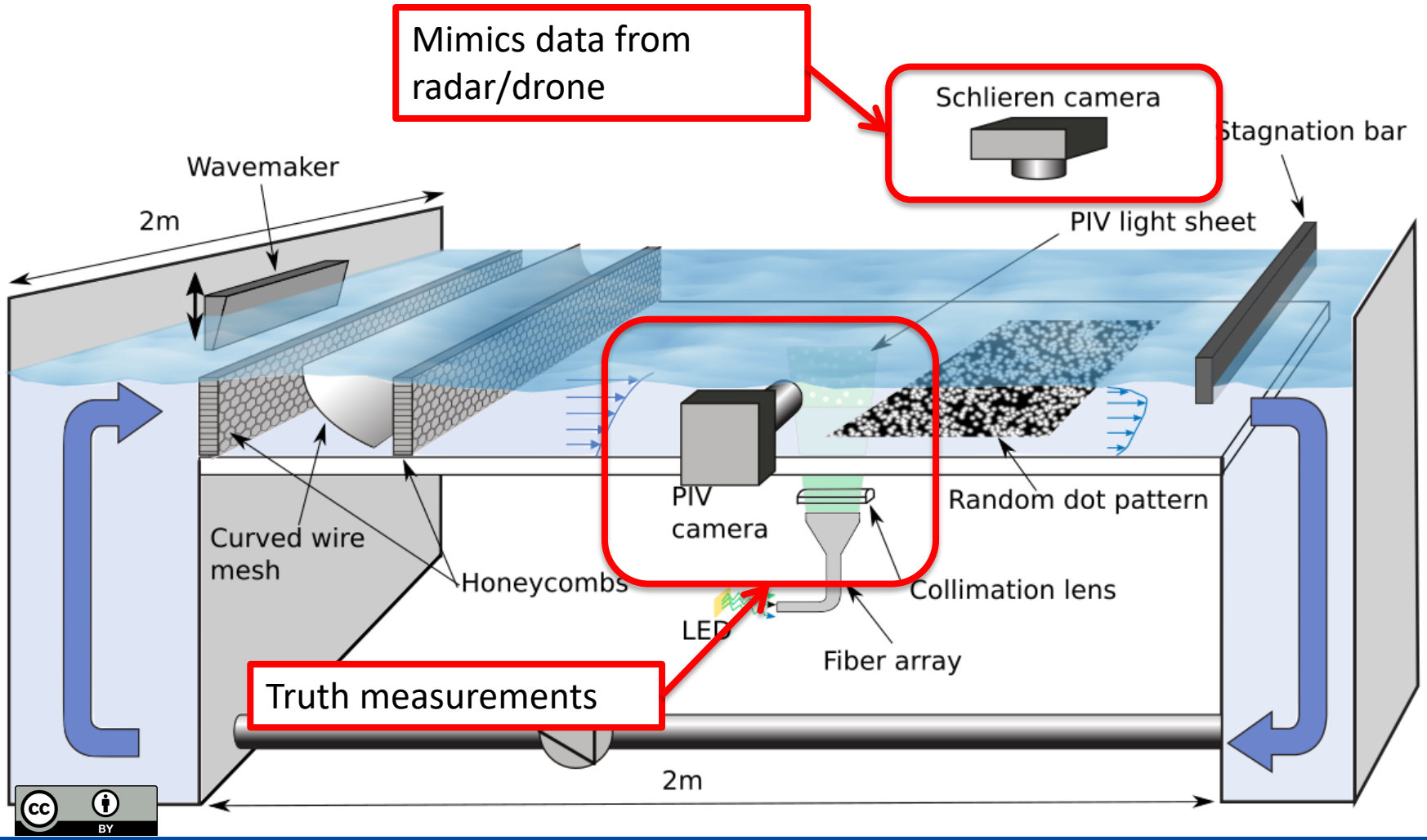
Inversion Methods: Conventional Method (EDM) vs. New Method (PEDM)

- The Doppler shift velocities are extracted from the wave spectrum at different wavenumbers, see example below-left (velocities along one horizontal direction). The conventional inversion method (EDM) assumes the Doppler shift at wavenumber *k* to equal the actual flow at some depth *Z*(*k*).
- However, the mapping function *Z*(*k*) is unknown a priori. A common approach is to assume a profile that varies linearly with depth. If the true profile has a different functional form (i.e. it is curved) such as in the example below, the mapping is not appropriate and the reconstructed profile will be inaccurate, demonstrated below-center comparing the blue circles (EDM) to the true profile (dashed black curve).
- Our new method, the PEDM, works to correct the velocities at each mapped depth based on a derived relation assuming a polynomial form to the current profile. In the example below-right, the PEDM works to shift the EDM velocities (blue circles) to the left, closer to the true profile.



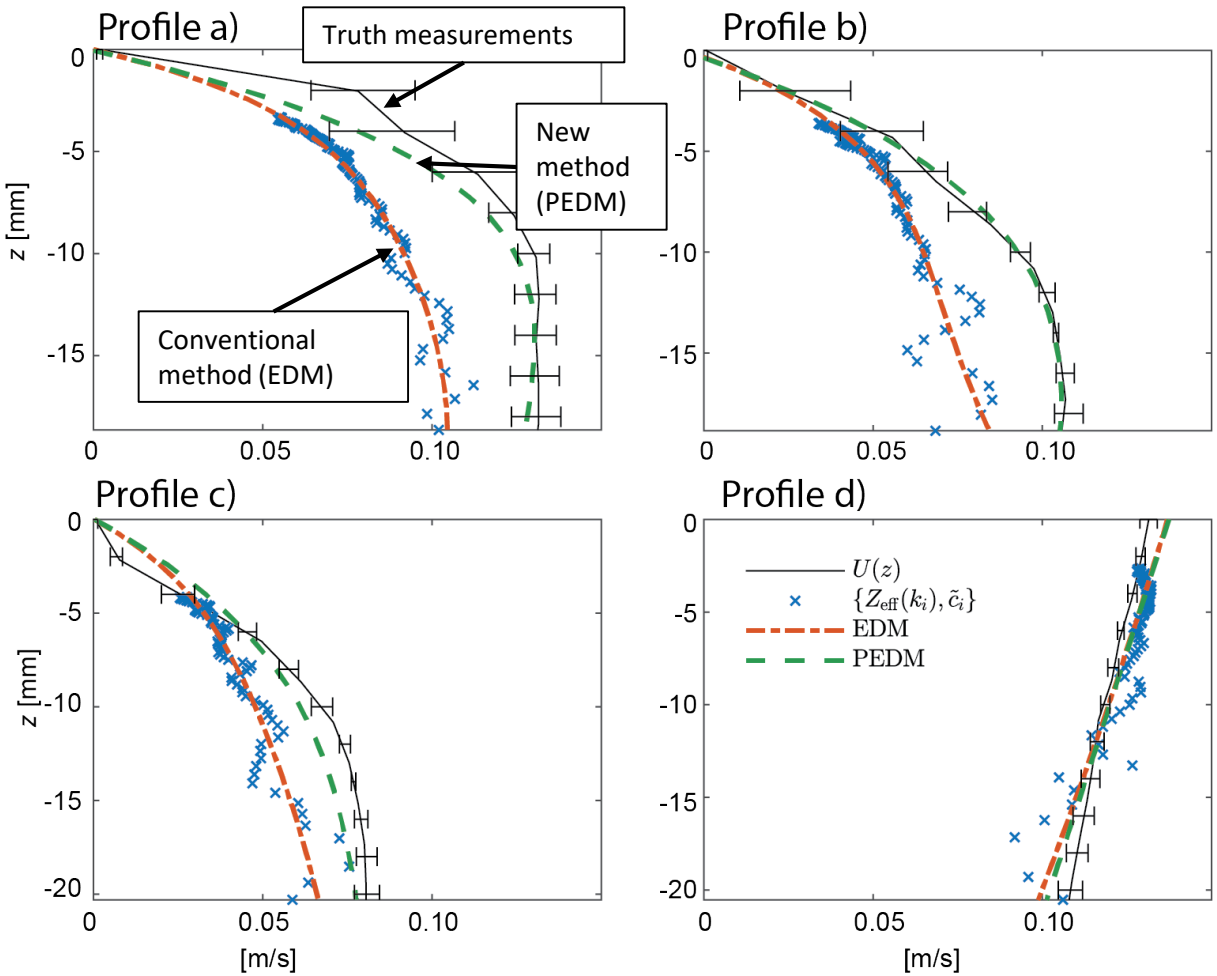
Our Work: Laboratory Setup

We test the PEDM on measured wave spectra in a laboratory where currents of different depth dependence could be well-controlled and measured independently using particle image velocimetry (PIV). Waves were measured using a synthetic Schlieren method, which measures the free surface gradient in space and time by imaging a pattern of random dots fixed below the surface.



Results

- The figures below show the PEDM applied to 4 cases of measured waves atop different current profiles. PIV 'truth' measurements are shown as the solid black curves.
- For profiles a-c) the PEDM results in a significant accuracy improvement relative to the conventional EDM mapping. For profile d), the current varies approximately linearly with depth, in which case the assumptions that are inherent to the EDM are fulfilled. In this case, the PEDM profile is approximately the same.



Profile	PEDM relative accuracy improvement
a)	3.8
b)	5.1
c)	4.8
d)	0.9

Outlook and References

- In the future we hope to apply the PEDM to field data collected by X-band radar, drones, or other techniques. We encourage anyone who is interested in potentially using the PEDM to get in touch with us.
  - Contact: Benjamin Smeltzer, **email: benjamin.smeltzer@ntnu.no**

- Code for implementing the PEDM will shortly be available as an option in the CopterCurrents library developed for finding currents from drone videos, developed by Ruben Carrasco, Michael Streßer, and Jochen Horstmann at Helmholtz-Zentrum-Geesthacht, Germany.
  - https://hzg.de/CopterCurrents
  - https://github.com/RubenCarrascoAlvarez/CopterCurrents

Current inversion references (selected examples):

PEDM:

1.) Smeltzer, B. K., Æsøy, E., Ådnøy, A., & Ellingsen, S. Å. (2019). An improved method for determining near-surface currents from wave dispersion measurements. Journal of Geophysical Research: Oceans, 124. https://doi.org/10.1029/2019JC015202

X-band radar:

2.) Lund, B., Graber, H. C., Tamura, H., Collins, C. O. III, & Varlamov, S. M. (2015). A new technique for the retrieval of near-surface vertical current shear from marine X-band radar images. Journal of Geophysical Research: Oceans, 120, 8466–8486. https://doi.org/10.1002/2015JC010961

3.) Campana, J., Terrill, E. J., & de Paolo, T. (2017). A new inversion method to obtain upper–ocean current–depth profiles using X-band observations of deep–water waves. Journal of Atmospheric and Oceanic Technology, 34, 957–970.

4.) Lund, B., Haus, B. K., Graber, H. C., Horstmann, J., Carrasco, R., Novelli, G., et al. (2020). Marine X-band radar currents and bathymetry: An argument for a wave number-dependent retrieval method. Journal of Geophysical Research: Oceans, 125, e2019JC015618. https://doi.org/10.1029/2019JC015618

Drones and other optical techniques:

5.) Streßer, M., Carrasco, R. & Horstmann, J. 2017 Video-based estimation of surface currents using a low-cost quadcopter. IEEE Geosci. Remote Sensing Lett. 14 (11), 2027–2031.

6.) Laxague, N. J. M., Özgökmen, T. M., Haus, B. K., Novelli, G., Shcherbina, A., Sutherland, P., et al. (2018). Observations of near-surface current shear help describe oceanic oil and plastic transport. Geophysical Research Letters, 45, 245–249. https://doi.org/10.1002/2017GL075891