Apports de la télédétection lidar infrarouge pour le suivi hydrodynamique et morphologique des systèmes littoraux

Kévin Martins

CNRS researcher at UMR 7266 LIENSs
La Rochelle University, France
kevin.martins@univ-lr.fr

Collaborators on this journey:

University of Bath: Chris Blenkinsopp
EPOC: Philippe Bonneton
IMB: David Lannes
LIENSs: Olivier de Viron
USACE: Katherine Brodie, Annika O'Dea
SIO: Julia Fiedler (now Hawaï Uni.)

Journée états de mer 2025

Brest, December 11, 2025

Vulnerability of the nearshore region to coastal hazards

Submersion

Erosion

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Submersion

Erosion

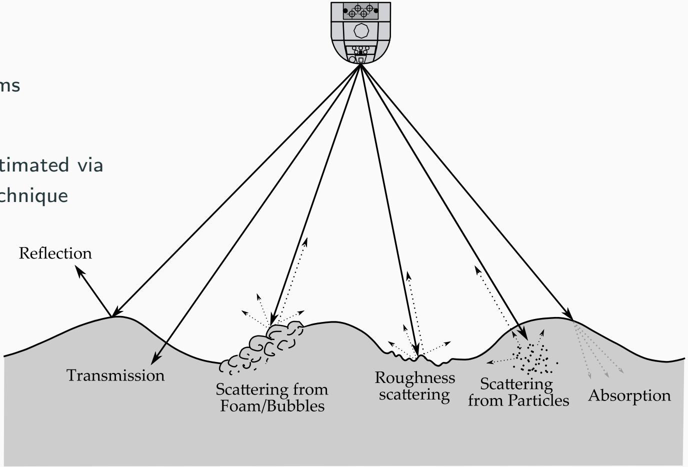
Major knowledge gap

Hydro-sedimentary dynamics under storm conditions still poorly understood

Lidar: Light detection and ranging

Typical applications:
- surveying
- detection systems

Principle: distance estimated via the 'time of flight' technique



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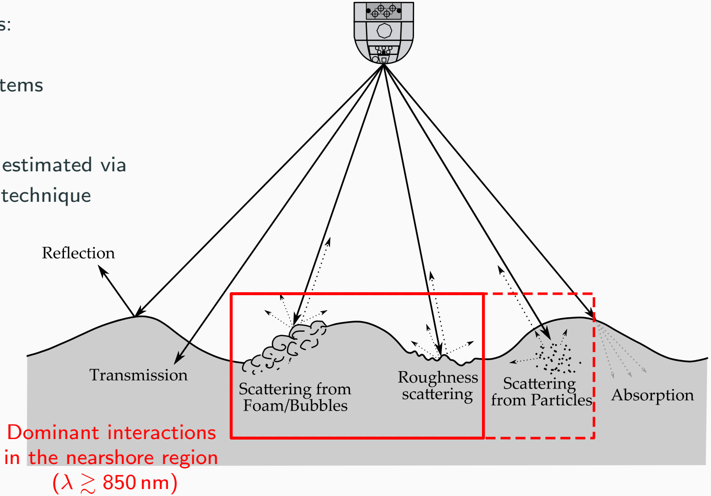
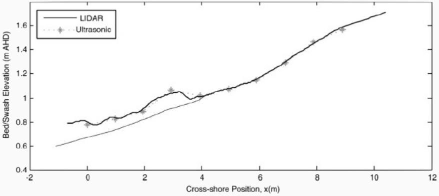


- **1999**: First measurements in the (very) nearshore by Irish et al. (2006)
  - ▷ 4-rangefinder lidar wave gauge (LWG) to estimate directional spectra

Deployment over the Field Research Facility pier at Duck, NC

- **2009**: First 2D scans of bores running up a sandy beach (Blenkinsopp et al., 2010).
  - ▷ High spatial ($\sim O$(mm) at nadir) and temporal (10-35 Hz) resolution
  - ▷ Ideal for capturing interactions at the shoreline



Test deployment at Narrabeen-Collaroy, Australia

- **2014-2017**: Analysing wave transformation in the surf zone with lidars.

PhD (2014-2017)

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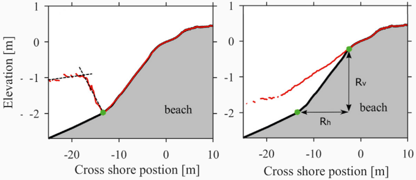

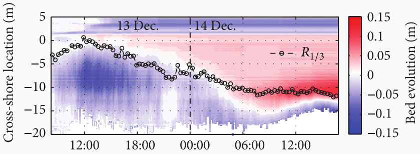

Martins et al. (2016, JS); Sous et al. (2016, AWR); Bergsma et al. (2019, CSR)

Measuring nearshore wave processes with lidars: a brief summary

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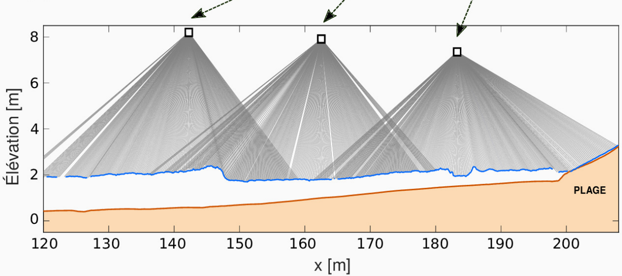
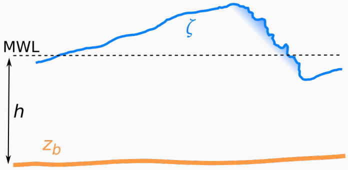
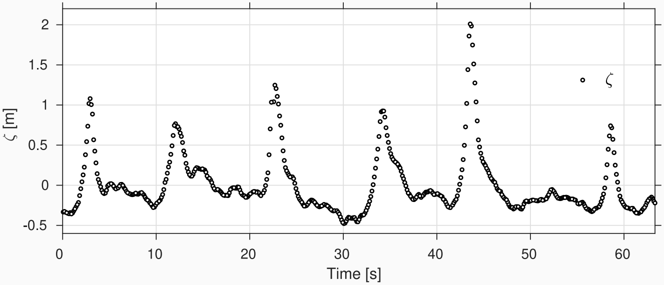


Measuring nearshore waves: direct or indirect methods?

Waves are measured through the free surface elevation ζ

- Heights, periods etc
- Total energy $E \sim \langle \zeta^2 \rangle$
- Repartition of energy across frequencies
- ...

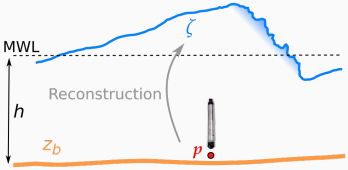


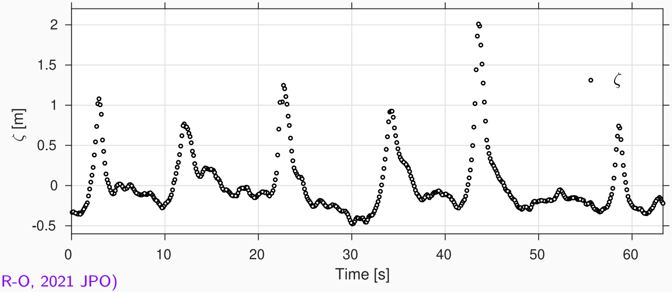


Measuring nearshore waves: direct or indirect methods?

Pressure transducers are the most common approach to estimate ζ:

- ▷ Robust and (was) cost-effective
- ▷ Indirect method





Martins et al. (2020 JGR-O, 2021 JPO)

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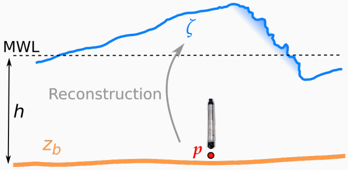
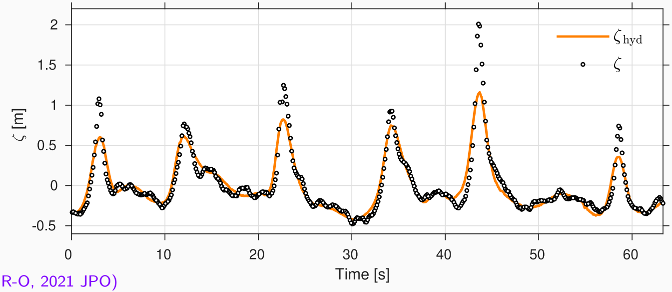


Hydrostatic reconstruction of ζ near breaking:

$$\zeta_{hyd} = (P - P_a)/\rho g - h_0$$

- ▷ Not adapted for wind seas and swell



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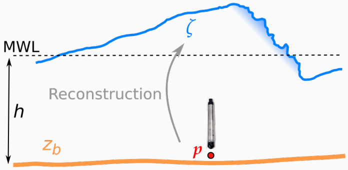
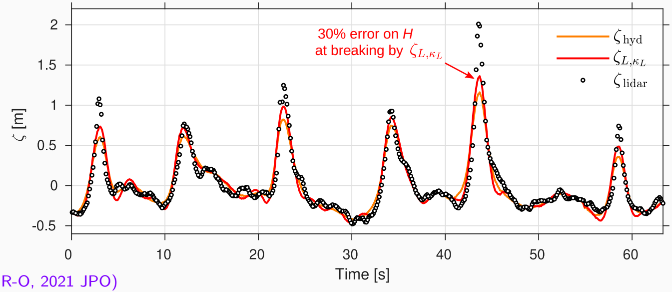
Classical linear reconstruction of ζ near breaking:

$$\widetilde{\zeta}_{L,\kappa_L}(\omega) = K_{p,L}(\omega)\,\widetilde{\zeta}_{hyd}(\omega)$$

$$K_{p,L}(\omega) = \frac{\cosh(\kappa_L h_0)}{\cosh(\kappa_L \delta_m)}$$

$$\omega^2 = g\kappa_L \tanh(\kappa_L h_0)$$





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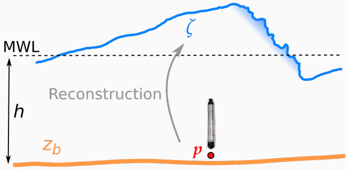
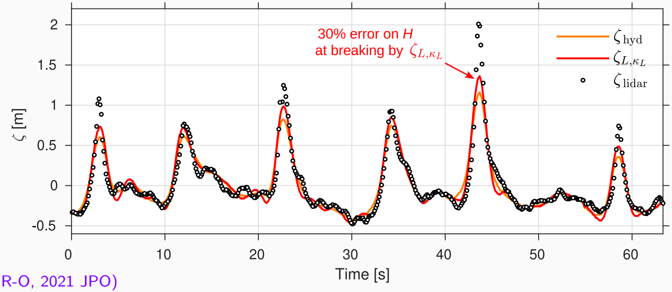


▷ **Not adequate** for wave-by-wave analysis and characterizing extreme waves



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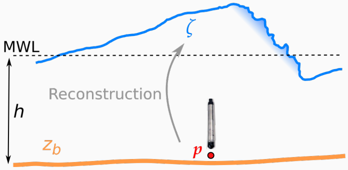
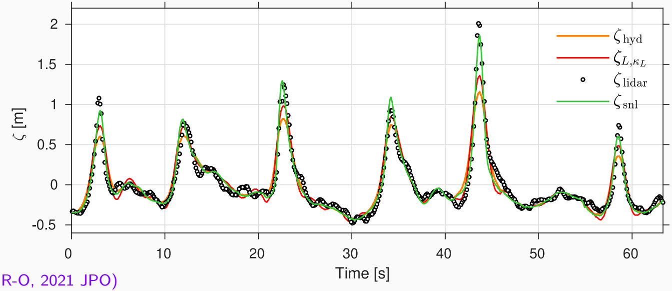
Weakly dispersive non-linear formula of Bonneton et al. (2018 CENG):

$$\zeta_{SL} = \zeta_{hyd} - \frac{h}{2g}\partial_t^2\zeta_{hyd}$$

$$\zeta_{SNL} = \zeta_{SL} - \frac{1}{g}\partial_t\left(\zeta_{SL}\partial_t\zeta_{SL}\right)$$





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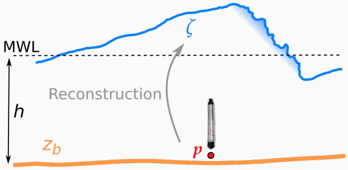
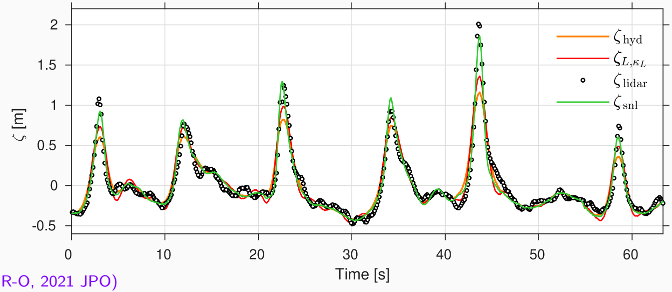


- ▷ For shallow water depths ($(\kappa_p h_0)^2 \lesssim 0.15 - 0.25$, $U_r \gtrsim 1$)
- ▷ **Adequate** for wave-by-wave analysis and easy to use (time-domain, no cutoff issue...)



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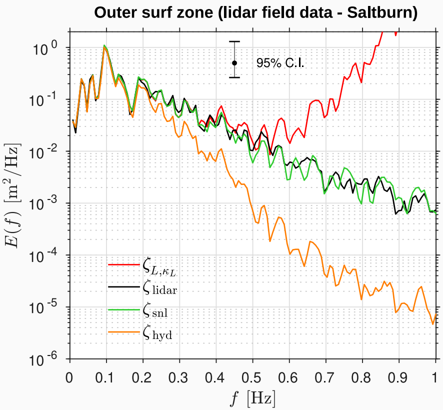

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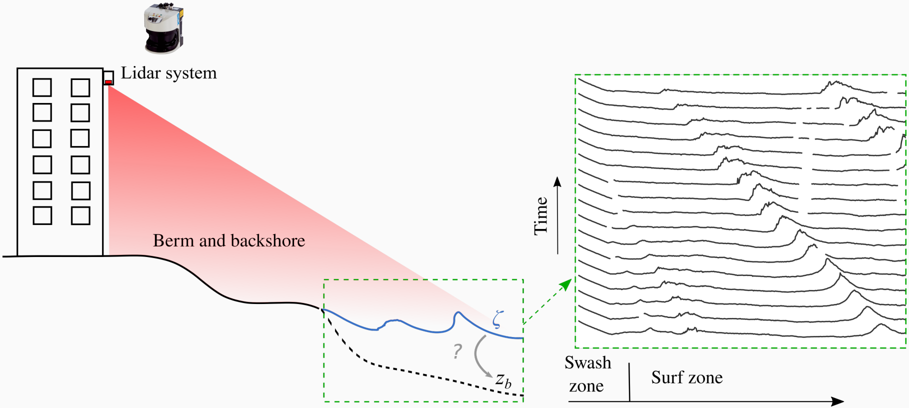
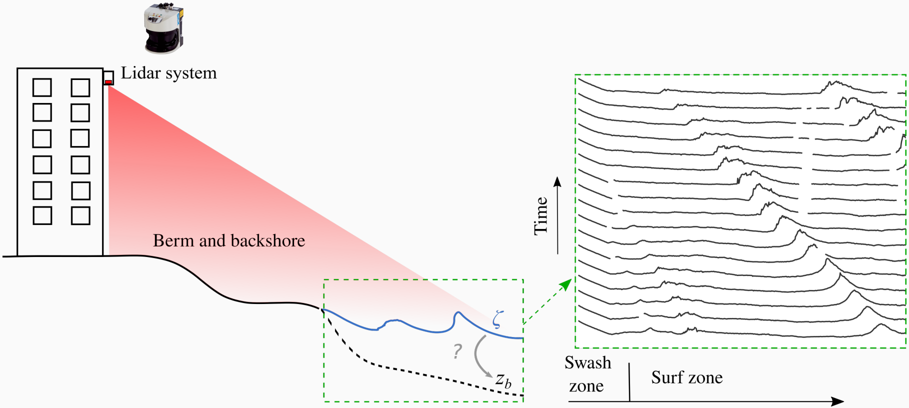
Depth-inversion of the nearshore region with remote sensing technology





Working principle:

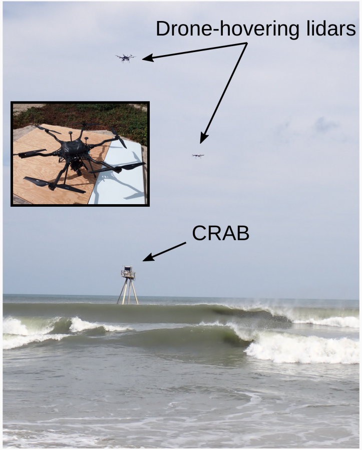
▷ Depth is found by "matching" observed $\kappa_{obs}(\omega)$ with theoretical $\kappa_{rms}(\omega)$ (Herbers et al., 2002):

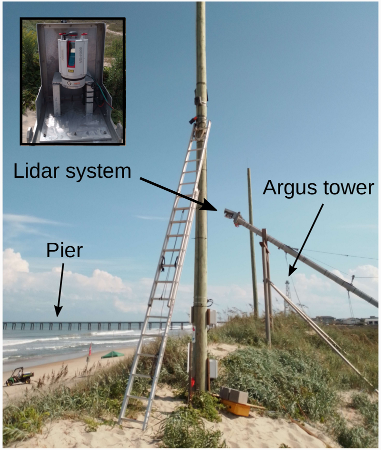
$$\kappa_{rms}(\omega) = \frac{\omega}{\sqrt{gh}}\sqrt{1 + \frac{h\omega^2}{3g} - \frac{3}{2hE(\omega)}\int_{-\infty}^{\infty} \mathrm{Re}\{B(\omega', \omega - \omega')\}d\omega'}$$

Martins et al. (2023, GRL)

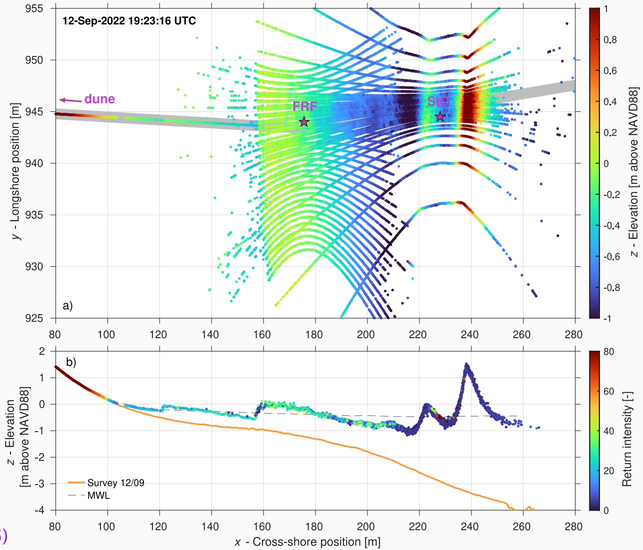
Collection of lidar & bathymetric data at Duck from 12 to 29 September 2022

- ▷ Validate/verify the Boussinesq-based depth-inversion (Martins et al., 2023) in the field using lidars





Sample of raw lidar data (flight #1, 12 September 2022)



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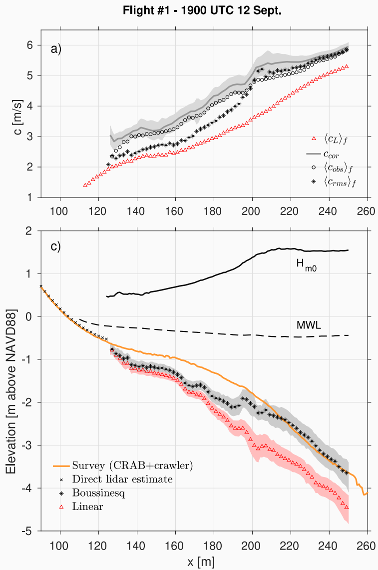
Field application at Duck, NC – Some results



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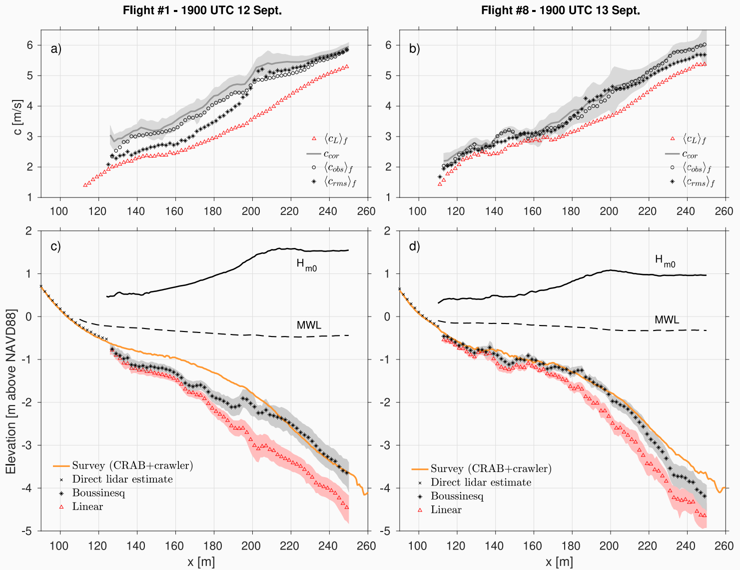

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Key messages:

- Lidar scanners are fantastic tools to analyse the temporal **and spatial** transformation of nearshore waves, including their runup and impact at the coast
- Main findings/works based on lidars so far:
  - more accurate and comprehensive datasets of surf zone waves (celerity, height, shape and so on...)
  - importance of non-hydrostatic and non-linear effects in nearshore waves dynamics
  - **question** what we knew and what we thought we knew about surf zone waves

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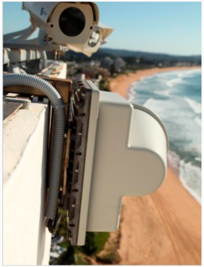
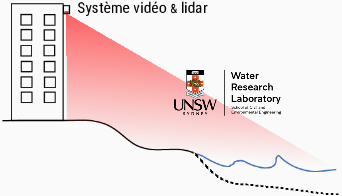
So many perspectives, including:

- Monitor beach topography(-bathymetry?) at many scales, from the wave groups to years
- Surf zone and swash dynamics during storms
- Characterization of wave impact and overtopping

Perspectives for cross-scale observation of nearshore processes

■ Remote-sensing stations at Duck NC (FRF) & Sydney, Australia, active for >10 years





▷ **Potential stations in France?**

- New lidar station at HORS (Japan) for on-demand runup monitoring (collab' UTokyo & PARI)

- Wave impact characterisation and wave runup & overtopping in Biarritz (collab' with UPPA)