# Towards Parametrized Modeling of the Current Vertical Structure during Extreme Events: Application to Alderney Race.


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## Introduction

This study aims to improve the parameterized modeling of the **current vertical profiles** in coastal environments **under strong tidal currents**. The primary study site is the Alderney Race in Normandy, France, which Hydroquest has selected to build a tidal farm.

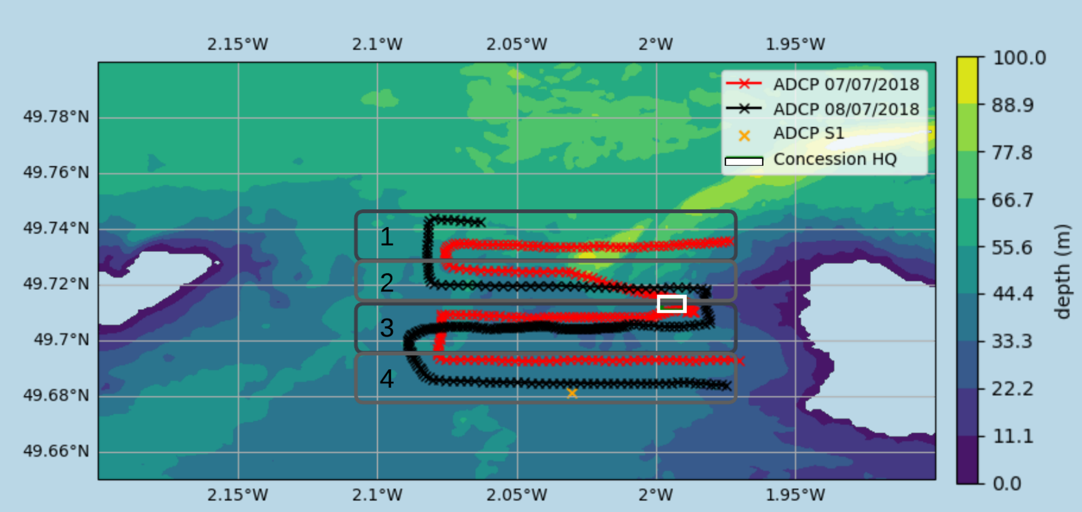
Past studies have shown significant **current variability and high turbulence production** due to interactions between hydrodynamics and seafloor topology in this area. Under extreme events, **waves and turbulence modify the current magnitude and direction** in the whole water column and not only in the bottom, making it hard to estimate accurately. (Bennis et al. 2022)

Existing parametric laws (used by industry) could be improved to **consider wave's effect** under extreme events in order to **improve the load assessment** of tidal turbines and other submerged structures.

## Study Site

**The Alderney Race :**

- Located between the Cape of la Hague and the island of Alderney,
- **Maximal tidal potential of 5.1 GW (Coles, Blunden, and Bahaj 2017),**
- **Strong sheared currents reaching up to 5 m/s** during equinoctial tides,
- Water depth in zone of interest : 30-40m




Map of the area with positions of the ADCP (towed in black and red and mounted in yellow) from Hyd2m ANR project (Furgerot et al. 2020) and location of the future tidal farm. Transects are numbered.

## Numerical Model

- **Three dimensional coupled model CROCO+WaveWatch III** described in Porcile et al. 2024.
- Wave current interaction is represented by the **vortex force formalism** introduced by McWILLIAMS, Restrepo, and Lane 2004
- **The wave-averaged, combined wave–current bottom stress** from Soulsby and Clarke 2005 is used.

## References


Bennis, A.-C. et al. (Mar. 2022). "A winter storm in Alderney Race: Impacts of 3D wave–current interactions on the hydrodynamic and tidal stream energy". *Applied Ocean Research* 120, p. 103009.

Coles, D.S., L.S. Blunden, and A.S. Bahaj (Apr. 2017). "Assessment of the energy extraction potential at tidal sites around the Channel Islands". *Energy* 124, pp. 171–186.

Furgerot, L. et al. (Aug. 21, 2020). "One year of measurements in Alderney Race: preliminary results from database analysis". *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 378.2178, p. 20190625.

McWILLIAMS, James C., Juan M. Restrepo, and Emily M. Lane (July 25, 2004). "An asymptotic theory for the interaction of waves and currents in coastal waters". *Journal of Fluid Mechanics* 511, pp. 135–178.

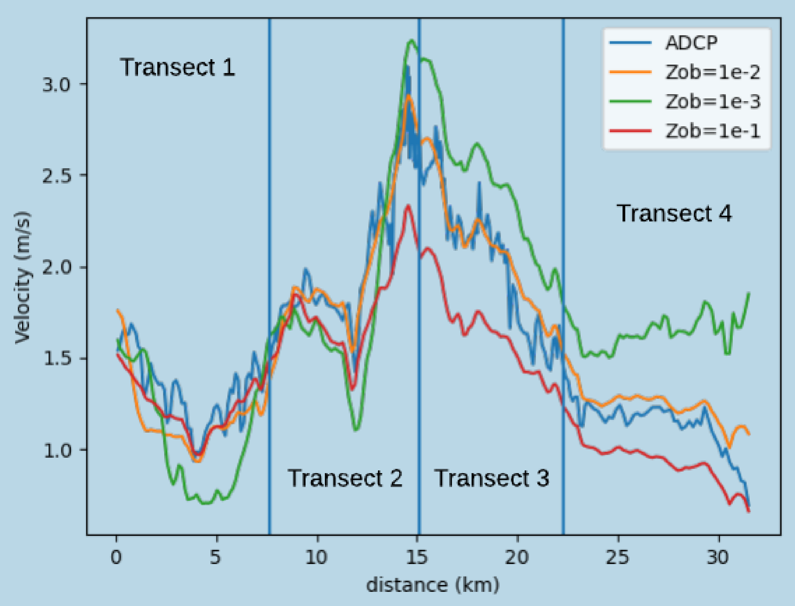
Porcile, Gaetano et al. (Apr. 16, 2024). "Implementation of additional spectral wave field exchanges in a three-dimensional wave–current coupled WAVEWATCH-III (version 6.07) and CROCO (version 1.2) configuration: assessment of their implications for macro-tidal coastal hydrodynamics". *Geoscientific Model Development* 17.7, pp. 2829–2853.

Soulsby, R L and S Clarke (2005). "Bed shear-stresses under combined waves and currents on smooth and rough beds".

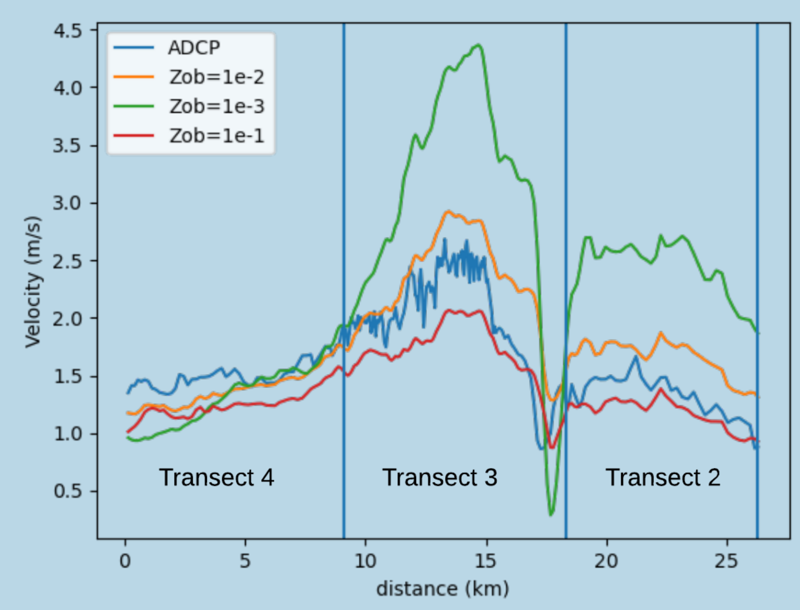

## Numerical Calibration with *in-situ* data

**The period of July 2018 was selected for two main reasons:**

- **The low wave height and wind speed** during this time allow for a focus on the contributions of bathymetry and tides to the current.
- **ADCP deployment** took place during this period, providing *in situ* data for validation.




a




b

| Transect | NRMSE at Flood | NRMSE at Ebb |
|---|---|---|
| 1 | 0.35 | / |
| 2 | 0.19 | 0.2 |
| 3 | 0.19 | 0.19 |
| 4 | 0.17 | 0.2 |

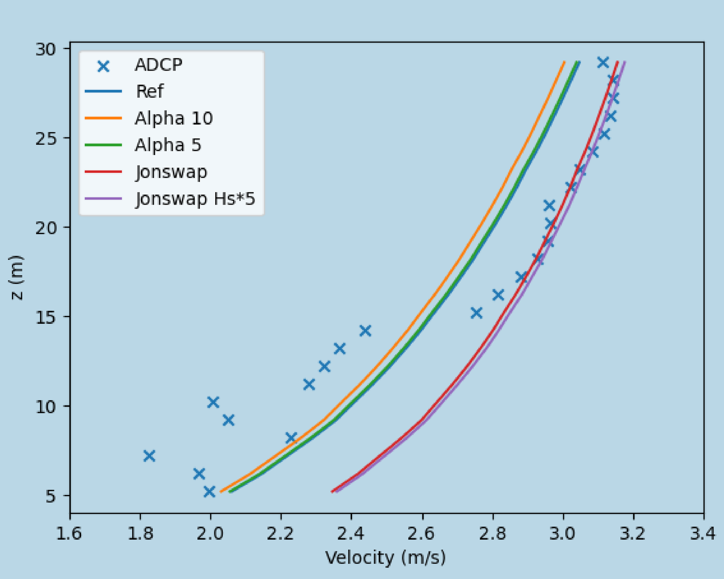
c

Barotropic horizontal velocity measured by the towed ADCP and from numerical simulations for various bottom roughness lengths $Z_{ob}$, versus distance traveled by the ADCP.(a) during flood (from 11:30AM to 3:30PM, July 7, 2018), and (b) during ebb (from 6:30AM to 10:30AM, July 8, 2018). (c) shows the NRMSE of the depth-dependent current amplitude along each transect for ebb and flood for $Z_{ob} = 1,5.10^{-2}$m.

## With Additional Wave Forcings

The wave spectra are artificially generated to test the model response to higher waves.

- **Ref**: the baseline configuration with $Z_{ob} = 1,5.10^{-2}$m.
- **Alpha 5** and **Alpha 10**: wave energy spectra multiplied by $\alpha^2 = 25$ and $\alpha^2 = 100$.
- **JONSWAP-type spectra** with a higher mean period to recreate swells (10 s compared to 3 s on average in the reference configuration).

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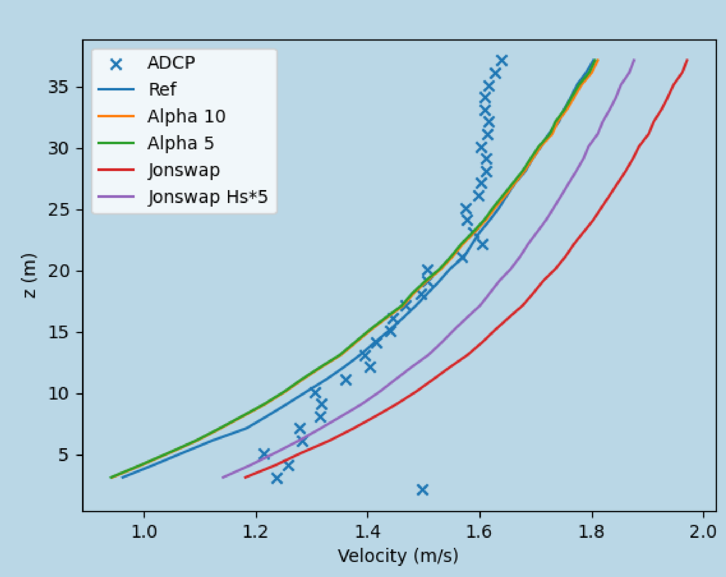


b

Measured (crosses) and modelled (solid lines) current vertical profiles at the center point of the future park. (a) at flood tide (1:10PM July 7) and (b) at ebb tide (9:56AM July 8).

The **overestimation of the velocity** for JONSWAP spectra is caused by the model, which **lowers the roughness length** for bottom orbital velocity exceeding a threshold value.

## Perspectives

1. There is still room to **improve the coupled model** by using spatially varying bottom roughness length and correcting the shift in roughness length for high orbital velocity.
2. To analyze additional wave-impacted scenarios, the next step involves simulating the **winter storm of January 2018**.