Accounting for Current in Wave Buoy Measurements

Project summary

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Background

• Buoys provide a vital source of wave information
  • Often used directly in design of offshore systems and ORE devices

• Buoy measurements used to calibrate and validate wide-area numerical models
  • Subsequently used for extreme and fatigue load calculations as well as power production (wave energy)

• Buoys do not (usually) measure current and assume there is no current
  • Wave parameters incorrect
  • Buoy response affected, unknown and unaccounted for

Source: https://www.ndbc.noaa.gov/
Motivation

Objectives
1. Quantify errors introduced by current
2. Account for current in buoy analysis approach

Motivation
Unknown current introduces 3 types of errors:

1. Wave climate misrepresented
   - Errors in assumed wavelengths, steepness, power

2. Errors in wave direction
   - Errors in mean direction and spreading

3. Alteration to buoy dynamics and ability to surface track
   - Transfer functions in current unknown
**Project overview**

**WP1: Obtain buoy transfer functions in current**
- Tank testing
  - Regular waves in current
  - 2 x buoy diameter
  - 2 x mooring stiffness
- Frequency domain model developed
  - Accounts for doppler shift and modified draught and mooring
  - Nemoh for hydrodynamic coefficients.

**WP2: Develop new buoy analysis approach to account for current**
- Method developed to correct wave parameters and estimate current velocity
  - Optimisation approach
- Considers current modification to wavenumber
  - Wavenumbers formulated as a function of angle relative to (unknown) current field

**WP3: Validate developed method**
- Method validated using simulated datasets
  - Predicts current velocity, directional spectra and corrects sea state parameters
- Preliminary validation using experimental data
- Plan to validate on full-scale data
  - ADCP near to wave buoy
WP1: Obtain buoy transfer functions in current

Experimental campaign

- 2 x buoy models manufactured
- 2 x moorings (for each buoy)
- Testing:
  - Current only (0 – 0.35 m/s)
  - Collinear waves and currents
  - Oblique waves and currents
  - Directionally spread waves and currents

Key findings 1: Vortex induced motions

- Vortex-induced motions significant
- Significantly lower frequency than waves
  - Amplitudes of wave-induced motions of buoy not affected by VIM

![Taut line vs Flexible line comparison]

Small buoy | Large buoy
WP1: Obtain buoy transfer functions in current

Numerical modelling

- Frequency-domain model developed to predict transfer functions
- Accounts for doppler shift, modified draught and mooring dynamics

Key findings 2: Predicting wave-induced buoy response

- Transfer functions developed to predict deviation from linear wave-current theory
- Function of:
  - Relative angles
  - Frequency
  - Velocity
WP1: Obtain buoy transfer functions in current

Numerical modelling
- Frequency-domain model developed to predict transfer functions
- Accounts for doppler shift, modified draught and mooring dynamics

Key findings 3: Wave-induced buoy response
- Buoy response deviates from linear wave-current theory in current
- Transfer functions (red) improve on predictions made by linear wave-current theory (black) compared to experiments (blue)
- (to be) incorporated into analysis framework
WP2: Develop new buoy analysis approach to account for current

- Formulated as a parameter estimation problem
  - Solve for unknown wave and current parameters, incorporating current

- Using a mesh adaptive direct search (MADS) algorithm

Framework

Testing on simulated data

- Can effectively resolve directional spectra
  - Including bi-modal

- Can predict current velocity
  - and correct sea state parameters
### WP3: Validate developed method

#### Tank data

<table>
<thead>
<tr>
<th>Transfer function</th>
<th>Target</th>
<th>Optimisation approach</th>
<th>Current estimate</th>
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<tbody>
<tr>
<td>$\vec{U} = 0.0 \text{ m/s}$</td>
<td><img src="image1" alt="Target" /></td>
<td><img src="image2" alt="Optimisation approach" /></td>
<td><img src="image3" alt="Current estimate" /></td>
</tr>
<tr>
<td>$\vec{U} = 0.15 \text{ m/s}$</td>
<td><img src="image4" alt="Target" /></td>
<td><img src="image5" alt="Optimisation approach" /></td>
<td><img src="image6" alt="Current estimate" /></td>
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- Preliminary analysis suggests method is performing well on experimental data
- Further tuning required (in progress) to improve estimates
- Transfer functions from WP1 not yet included, which will further improve performance

#### Full-scale data

- Data obtained
  - Wave buoy with ADCP nearby to validate current estimates
- Data processing begun
- No validated tests carried out to date
### Key impacts and follow on work

<table>
<thead>
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<th>Key impacts</th>
<th>Further work</th>
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<tbody>
<tr>
<td>• Errors associated with the effect of current on wave buoys quantified</td>
<td>• Validation on real ocean datasets</td>
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</table>
| • Method developed to account for the presence of current  
  • Can correct historic datasets  
  • Improved estimates of wave parameters + estimate of current | • Development of time-domain model to capture non-linearities associated with buoy response |
| • Numerical modelling approach developed to predict modified buoy response in current  
  • Can improve estimates further  
  • Expand understanding of, and correction for, different buoys and mooring configurations | |

### Future project options

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| • Large-scale correction of historic buoy datasets  
  • Subsequent large-scale assessment of wave-current interaction  
  • Validation of coupled wave-current models with corrected buoy datasets (improved approach)  
  • Development of robust open-source code, including all buoy configurations, for improved analysis | |

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