Analysis of Shallow Water Wave Measurements Recorded at the Field Research Facility

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Motivation of Study

- Part of the NOPP project funded by ONR
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- Wave height with given return period is required for designing coastal structures
  - Wave height probability distribution
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- Hindcast data is typically available in deep water but not shallow depths.
  - Evolution of frequency spectrum
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- Wave height with given return period is required for designing coastal structures
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- Hindcast data is typically available in deep water but not shallow depths.
  - Evolution of frequency spectrum
- Low-frequency waves cause erosion, excite harbour seiches, break ice shelves & cause resonance of moored vessels
  - Infragravity wave prediction
Methodology

- Field measurements with 34 mins sample duration
- Wave height probability distribution
  - Zero-crossings and ranking wave heights
- Evolution of frequency spectrum
  - Welch method for ensemble averaging of spectrum
- Infragravity wave prediction
  - Run Ideal Surf Beat (IDSB) model
Summary of Conclusions

- Wave height distribution
  - Performed a Kolmogorov-Smirnov test on 1442 individual sea states
  - Glukovskiy distribution (as formulated by van Vledder, 1991) provided best fit to data

- Evolution of frequency spectrum
  - TMA spectrum was not comparable with the field measurements, especially for low frequencies
  - Greater attenuation with larger spectral density for all ranges of $kd$

- Infragravity wave prediction
  - Ideal Surf Beat (IDSB) model has an average skill of 78%
Field Measurements: Location

- Duck, North Carolina, USA
Field Measurements: Cases Examined

- **Instruments**
  - Nortek Aquadopp (ADOP)
  - Nortek Acoustic Wave And Current (AWAC) meters
  - Sample at 2 Hz for 34 mins every hour

- Data available for 1442 sea states in 5 storm events

<table>
<thead>
<tr>
<th>Case</th>
<th>Date</th>
<th>Max. $H_s$ [m]</th>
<th>Mean $T_p$ [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>01–05 September 2010</td>
<td>3.2</td>
<td>12.3</td>
</tr>
<tr>
<td>E2</td>
<td>21–23 August 2009</td>
<td>3.3</td>
<td>15.1</td>
</tr>
<tr>
<td>E3</td>
<td>11–16 November 2009</td>
<td>3.0</td>
<td>12.0</td>
</tr>
<tr>
<td>E6</td>
<td>26–28 March 2009</td>
<td>2.9</td>
<td>13.6</td>
</tr>
<tr>
<td>E8</td>
<td>29–30 August 2010</td>
<td>1.7</td>
<td>12.7</td>
</tr>
</tbody>
</table>

- Case E2 corresponds to Hurricane Bill
Field Measurements: Bathymetry

The image shows a cross-sectional view of a coastal area with various bathymetric features. The cross-section includes annotations for different measurement points labeled AD1, AD2, AW1, AW2, AW3, and AW4. The elevation and cross-shore distance are plotted, with depth indicated by the negative values on the vertical axis. The data is likely used for analyzing shallow water wave measurements recorded at the FRF (Fay Renewable Energy Facility).
Wave Height Distribution

- **Theoretical distributions**
  1. Rayleigh: $f(H_s)$
  2. Forristall (1978): $f(H_s)$
  3. Glukhovskiy (formulation of van Vledder, 1991): $f(H_s, d)$
  4. Battjes and Groenendijk (2000): $f(H_s, d, \alpha)$

- Distributions 1 and 2 are for deep water
- Distributions 3 and 4 were developed specifically for shallow water
- Battjes-Groenendijk distribution is a composite Weibull in 2 parts
- None of the distributions has an upper limit

- **Analysis**
  - Visual inspection for individual sea states
  - Kolmogorov-Smirnov test for goodness of fit
Example Probability Distributions for Individual Sea States

- $H_s = 2.54 \text{ m}, T_p = 17.00 \text{ s} \& d = 5.59 \text{ m}$
- $H_s = 2.90 \text{ m}, T_p = 15.48 \text{ s} \& d = 7.23 \text{ m}$
- $H_s = 2.85 \text{ m}, T_p = 15.36 \text{ s} \& d = 9.05 \text{ m}$
- $H_s = 3.03 \text{ m}, T_p = 15.07 \text{ s} \& d = 12.25 \text{ m}$
Test Statistic from K-S Test: Histograms

Rayleigh

Forristall

Glukhovskiy

Battjes–Groenendijk

Test statistic [-] vs Number of events [-] for different distributions.
### Test Statistic from K-S Test: Summary

#### Summary of test statistic, $k^*$

<table>
<thead>
<tr>
<th>Distribution</th>
<th>Mean $k^*$</th>
<th>Mode $k^*$</th>
<th>Median $k^*$</th>
<th>Std $k^*$</th>
<th>Pass [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rayleigh</td>
<td>0.094</td>
<td>0.059</td>
<td>0.082</td>
<td>0.044</td>
<td>87</td>
</tr>
<tr>
<td>Forristall</td>
<td>0.104</td>
<td>0.091</td>
<td>0.092</td>
<td>0.051</td>
<td>80</td>
</tr>
<tr>
<td>Glukovskiy</td>
<td>0.075</td>
<td>0.063</td>
<td>0.069</td>
<td>0.030</td>
<td>96</td>
</tr>
<tr>
<td>Battjes-Gronendijk</td>
<td>0.089</td>
<td>0.059</td>
<td>0.084</td>
<td>0.033</td>
<td>91</td>
</tr>
</tbody>
</table>

Glukovskiy has the best agreement with the field measurements.
Evolution of Frequency Spectrum

- Frequency resolution of 0.01 Hz
- Analyse spectral evolution of the frequency variance density spectra in time and space
- Focus on difference between spectra at 11 m & 5 m AWACs
- Calculate the gain between the two spectra
- Compare gain to TMA transfer function
Mean Gain

- Calculate difference between frequency spectrum at 11 m and 5 m
- Take the mean of this difference
- Compare to TMA transfer function between 11 m and 5 m

![Graph showing frequency vs. gain for different measurements and TMA transfer function.]

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Analysis of Shallow Water Wave Measurements Recorded at the FRF
Attenuation

- Temporal Evolution
- Mean Gain
- Attenuation

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Analysis of Shallow Water Wave Measurements Recorded at the FRF
Ideal Surf Beat (IDSB) Model

- Infragravity waves have period between 20 s & 200 s
- IDSB can simulate generation of bound and free infragravity waves
  - Reniers et al. (2002) JGR
- Assumptions
  - Linear shallow-water wave model
  - Constant along shore bathymetry
  - Full reflection of IG waves at shoreline
  - Narrow spectrum in both frequency and direction
- Incoming and outgoing waves
  - Incoming directionally-spread short waves
  - Incoming *bound* IG waves
  - Outgoing trapped and leaky *free* IG waves
Calculated vs Measured: Case E2

(a) Short waves

(b) Infragravity waves
Calculated vs Measured: Case E6

- **(c) Short waves**
- **(d) Infragravity waves**
Calculated vs Measured: Case E8

(e) Short waves

(f) Infragravity waves
Calculate vs Measured: Table

- Determine the skill, $s$, at each instrument and overall
  \[
  s = 1 - \sqrt{\frac{\langle (H_{rms,m} - H_{rms,c})^2 \rangle}{\langle H_{rms,m}^2 \rangle}}
  \]

<table>
<thead>
<tr>
<th>Case</th>
<th>AW4</th>
<th>AW3</th>
<th>AW2</th>
<th>AW1</th>
<th>AD2</th>
<th>AD1</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>E2</td>
<td>0.78</td>
<td>0.83</td>
<td>0.78</td>
<td>0.73</td>
<td>-</td>
<td>-</td>
<td>0.78</td>
</tr>
<tr>
<td>E6</td>
<td>0.78</td>
<td>0.75</td>
<td>0.74</td>
<td>0.81</td>
<td>-</td>
<td>-</td>
<td>0.77</td>
</tr>
<tr>
<td>E8</td>
<td>0.83</td>
<td>0.78</td>
<td>0.74</td>
<td>0.75</td>
<td>0.8</td>
<td>0.81</td>
<td>0.79</td>
</tr>
</tbody>
</table>

- Average skill of 78%
Conclusions

- Analysed new shallow water measurements at FRF
  - Data available for 1442 sea states in 5 storm events
- Wave height distribution
  - Performed a Kolmogorov-Smirnov test on every sea state
  - Glukovskiy distribution (as formulated by van Vledder, 1991) provided best fit to data
- Evolution of frequency spectrum
  - TMA spectrum was not comparable with the field measurements, especially for low frequencies
  - Greater attenuation with larger spectral density for all ranges of $kd$
- Simulating infragravity waves with Ideal Surf Beat (IDSB) model
  - Average skill of 78%
Acknowledgements

- ONR for providing funding for NOPP project
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