Non-hydrostatic modelling of extreme water levels on Banneg island, France

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Why are we interested in extreme water levels?

Giant waves at Porthleven, UK, on February 5 2014 (Hercule storm)
Banneg island: an adequate “laboratory”

Bathymetry of Banneg island

Bathymetry of Molene Archipelago

 Anthony Penel
Geomorphological evidences of the extreme hydrodynamic activity occurring on Banneg island (Suanez et al., 2009; Fichaut and Suanez, 2011)

Can you spot the differences between the two pictures?
Displaced blocks between 2008/04 - 2014/04 (mostly during 2013/14 winter)
Presentation outline

1. Hydrodynamic measurements
   - Instruments deployment
   - Wave heights in February 2014
   - Water levels on February 5 2014

2. SWASH modelling
   - Model description and implementation
   - Model validation against observations

3. Model results
   - Extreme water levels on February 5 2014
   - Propagation of infragravity waves

4. Conclusion & Perspectives
Hydrodynamic measurements

Instruments deployment
Wave heights in February 2014
Water levels on February 5 2014

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Model results
Extreme water levels on February 5 2014
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Conclusion & Perspectives
Hydrodynamic measurements

Instruments deployment

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Extremes water levels modelling

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Hydrodynamic measurements

Instruments deployment

Location of instruments

Nearshore elevation time series
- February 2014: stormiest month of the year (decade?) with $H_m_0 > 3 \text{ m}$ 46% of the time and $H_m_0$ over 8 m on February 5 and February 14
- Significant 12-hr modulation of offshore wave parameters
- Strong 12-hr and fortnight modulation of $H_m_0$ in the surfzone
- Very high infragravity energy levels in the surf zone ($H_m_0_{inf}$ up to 2 m)
- Tidal modulation and asymmetry of $H_m_0_{inf}$ in the surfzone

Time-series of spectral density, incident and infragravity $H_m_0$ on February 2014
Hydrodynamic measurements

Water levels on February 5 2014

Water levels at CS1 on February 5 2014

Water levels at CS3 on February 5 2014

Depth (m relative to chart datum)

0 5 10 15

Depth above sensor (m)

0 2 4 6 8 10

Max. water level

Max. water level

Predicted tide

Elevation (m a.c.d)

0 5 10 15

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Extreme water levels modelling

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SWASH (Simulated WAves till SHore), Zijlema et al., 2011

\[
\begin{align*}
\frac{\partial u}{\partial t} + \frac{\partial uu}{\partial x} + \frac{\partial wu}{\partial z} &= -\frac{1}{\rho} \frac{\partial (p_h + p_{nh})}{\partial x} + \frac{\partial}{\partial x} \left( \nu_h \frac{\partial u}{\partial x} \right) + \frac{\partial}{\partial z} \left( \nu_v \frac{\partial u}{\partial z} \right) \\
\frac{\partial w}{\partial t} + \frac{\partial uw}{\partial x} + \frac{\partial ww}{\partial z} &= -\frac{1}{\rho} \frac{\partial (p_h + p_{nh})}{\partial z} + \frac{\partial}{\partial x} \left( \nu_h \frac{\partial w}{\partial x} \right) + \frac{\partial}{\partial z} \left( \nu_v \frac{\partial w}{\partial z} \right) - g \\
\frac{\partial u}{\partial x} + \frac{\partial w}{\partial z} &= 0
\end{align*}
\]

Implementation to Banneg island

- 2DV profiles with 0.5 m resolution, starting in 50 m depth (waverider), intersecting pressure gauges, and ending at the centre of the island
- Two vertical layers (accuracy ok for dispersive effects up to 0.2 Hz)
- Spectral forcing based on waverider observations
- Constant water level estimated from tide gauge observations
- Time step comprised between 0.0015 - 0.006 s (CFL < 0.5)
### Elevation and offshore wave parameters of 6 selected storms

<table>
<thead>
<tr>
<th>Date</th>
<th>Elevation (m amsl)</th>
<th>Hm0 (m)</th>
<th>Tp (s)</th>
<th>Direction (°)</th>
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<tbody>
<tr>
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<td>5.0</td>
<td>16.7</td>
<td>264</td>
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<tr>
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<td>9.0</td>
<td>18.2</td>
<td>262</td>
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<td>8.4</td>
<td>13.3</td>
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<tr>
<td>2014/02/18</td>
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<td>2.5</td>
<td>11.1</td>
<td>270</td>
</tr>
<tr>
<td>2015/02/20</td>
<td>3.9</td>
<td>2.9</td>
<td>16.7</td>
<td>267</td>
</tr>
<tr>
<td>2015/02/24</td>
<td>2.6</td>
<td>4.1</td>
<td>18.2</td>
<td>264</td>
</tr>
</tbody>
</table>

#### Comparison of modelled and observed wave spectra

![Wave spectra comparison](image_url)
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Simulated water levels for the conditions of February 5 2014
Profiles of water elevation, incident and infragravity wave height, mean water level, shoreward and seaward incident and infragravity energy fluxes
Shoreward/seaward energy fluxes, Sheremiet et al., 2002

\[
F^{\pm}(f, x) = \frac{\sqrt{gh}}{4} \left[ C_{pp}(f, x) + \left( \frac{h}{g} \right) C_{uu} \pm \left( 2\sqrt{\frac{h}{g}} \right) C_{pu}(f, x) \right]
\]

\[
F_{inc}^{\pm}(x) = \int_{0.04\text{Hz}}^{2.5\text{Hz}} F^{\pm}(f, x) df
\]

\[
F_{infra}^{\pm}(x) = \int_{0.01\text{Hz}}^{0.04\text{Hz}} F^{\pm}(f, x) df
\]

Profiles of water elevation, incident and infragravity wave height, mean water level, shoreward and seaward incident and infragravity energy fluxes
**Conclusion**

- Hydrodynamic measurements revealed large waves off Banneg island and potential submersion of the island during winter 2013/14
- The SWASH model was shown to reproduce correctly the wave propagation during episodes of high water levels (wave + tide)
- Episodic submersions of the island were reproduced by the model on February 5 2014
- Infragravity waves were shown to be strongly reflected at the coastline

**Perspectives**

- Correlation between hydrodynamic data and geomorphological changes
- 3-D modelling with SWASH
- Infragravity wave dynamics on steep cliffs
Thank you for your attention!

Soil erosion and storm deposits after the overwashing of the island in February 1990
Credits : Bernard Hallegoüet