The Wave Climate of Ireland: From Averages to Extremes

Sarah Gallagher, Met Éireann

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• Motivation & Introduction

• Methodology - How can we Model Waves?

• The Present Wave Climate of Ireland

• The Future Wave Climate of Ireland

• Final Thoughts
Motivation & Introduction
Irish Atlantic Coast & the Harsh Environment

Photo: Sean Curtin

3rd of January 2014. Photo: George Karbus

6th of January 2014. Photo: Sarah Gallagher

Irish Atlantic Coast and the Energy Potential

Approximate global distribution of wave power levels. Wave power levels given as KW/m of wave front. (Source: http://www.oceanenergy.ie/images/world-map.jpg)
Wave Energy

- Potential for both wind & wave renewable industry
- An energetic wave climate: potentially harsh environment!
- Detailed knowledge of climate desirable – can OE be viable?
- How might the wave climate change in the future?

Figure: Left panel: an artist’s impression of an array of the Oyster® Oscillating Wave Surge Converter (OWSC), developed by Aquamarine Power Ltd. Right panel: the Oyster 800 wave energy converter at the European Marine Energy Centre (EMEC) in Orkney. Image courtesy of http://www.aquamarinepower.com.
What is “Wave Climate”?

- The **Earth climate** system is a **complex**, coupled system: the atmosphere, land, snow/ice, oceans and the biosphere

- Climate is defined loosely as **averaged** weather: mean and variability over time scales ranging from seasons to millennia

- Wave climate is the averaged condition of the waves over a period of years -- shown by parameters such as **wave height**, **period**, and **direction**

Source: [http://paos.colorado.edu/~toohey/Fig_25.jpg](http://paos.colorado.edu/~toohey/Fig_25.jpg)
A **gap** in our **knowledge** of the wave climate?

- Lack of regional/local long term wave climate studies – **climate variability**
- **Buoy observations** sparse (from 2001)
- Nearshore wave buoys (from 2008)
- **Satellite** wave data: since 1992 - low temporal resolution
Wave Forecasting Models
Can we Predict the “Giants” among Waves?

- Can **wave forecasting models** capture such formidable waves?

- Wave forecasting has experienced much **progress** in recent decades:
  - better understanding of the underlying **physical processes**
  - **Observations** at a global scale (satellite measurements)

- Key Limitation: **disparity in the scales** (ocean basins vs. waves)


Wave Forecasting Models

- Models cannot afford to predict individual waves (over large areas): describe **evolution of the sea-state**

- **Key Inputs:** Bathymetry & 10m wind fields

- **Statistics** of wave heights, periods over set time frames (e.g. 30 min) - ‘Wave Action Balance Equation’

- Numerical models run at HPC center (e.g. ICHEC)
Present Wave Climate of Ireland
WAVE HEIGHTS

• In **winter**: Atlantic coast exposed to highly energetic sea’s:
  – **mean SWH 5m**

• In contrast, mean SWH values do not exceed **2m** in the **Irish Sea**

• Large inter-annual variability:
  • up to **10%** for **annual** means
  • over **20%** in **winter & spring**
WAVE HEIGHTS - A **regional** close up!
WAVE PERIODS
Irish Wave Climate

- A long history of large waves: **storm to freak waves**
- Prevalent strong **winds** - Atlantic **fetch**:


OBSERVATIONAL RECORD

- **Largest wave** recorded on the 12th Feb 2014 at the Kinsale Energy Gas Platform: **25m individual wave** in a Significant Wave Height* of **12m**

*Significant Wave Height (SWH) = mean wave height (trough to crest) of the highest third of the waves

Next Highest: **23.4m wave** with **SWH 14.65m at M4** (6th Jan 2007)
WAVE Extremes

Note: Highest SWH: 17.2m M6 (9th Dec 2007)

- Left panel: **100-year return period** (value exceeded once every $n=100$ years) for **annual maxima** (AM) of SWH (m) -- using a GEV distribution

- Centre & right panels: lower & upper confidence bounds of the return period at the 95% confidence interval level

The WMO defines SWH >14m as a **PHENOMENAL** sea-state!
Future Wave Climate of Ireland
EC-EARTH: A NUMERICAL EARTH SYSTEM MODEL

• Consortium to study climate change under defined emission scenarios: Representative Concentration Pathways (RCP’s)

Source: IPCC AR5 Chapter 1 (Cubasch et al., 2013)

[ EC-Earth: atmospheric (ECMWF IFS); oceanic (NEMO); sea-ice (LIM2) & land surface (HTESSEL) ]

• RCP4.5 & RCP8.5 10m winds & ice-fields to drive wave model
• Time period 1980-2009 vs. 2070-2099 (30-year averages)
WAVE HEIGHTS

- Projected future changes in SWH (m) to the **end of 21st century**

- Left panels: Averaged historical multi-model **annual** (a), **winter** (c) & **summer** (e) means of SWH (m) (1980–2009)

- Right panels: averaged wave model ensemble **projected changes** in SWH (m) for **RCP8.5** (2070–2099)

Hatching: where the magnitude of wave model ensemble difference exceeds twice the inter-model standard deviation
WAVE Extremes

- Projected future changes in highest 5% of SWH (m) to the end of 21st century

- Left panels: Averaged historical multi-model annual (a), winter (c) & summer (e) 95th-percentile of SWH (m) (1980–2009)

- Right panels: averaged wave model ensemble projected changes in SWH (m) for RCP8.5 (2070–2099)

Hatching: where the magnitude of wave model ensemble difference exceeds twice the inter-model standard deviation
Can this decrease be linked to North Atlantic winds?
STORM TRACKS - CROSSING THE ‘IRISH BOX’

- Left: EC-Earth projections (RCP8.5) -- Tracks of storms crossing Irish ‘box’ with pressure <970hPa.
- Top panel: 2010-2038 (53 tracks)
- Bottom panel: 2071-2099 (59 tracks)
Final Thoughts
• **Present wave climate**: A strong spatial & seasonal variability was found for SWH (up to 10-15% annually)

• Energetic waves off west coast: **Phenomenal** sea-states!

• **Accessibility** for marine operations can be **low** due to energetic wave climate esp. in **winter** - careful planning for OE

• **Future wave climate**: A general **decrease** (up to 15%) was found in mean and larger ‘storm-waves’ (e.g. 95th-percentile) for annual, summer & winter values of SWH towards the end of the 21st century for **RCP8.5**
Thank you for listening...

Any Questions?
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Aileen’s wave at the Cliffs of Moher, Co. Clare