The Wave Climate of Ireland: From Averages to Extremes

Sarah Gallagher, Met Éireann

IMS One Day Conference: ***The Perfect Storm***, 28th March 2015

- Motivation & **Intro**duction
- Methodology - How can we **Model** Waves?
- The **Present** Wave Climate of Ireland
- The **Future** Wave Climate of Ireland
- Final **Thoughts**

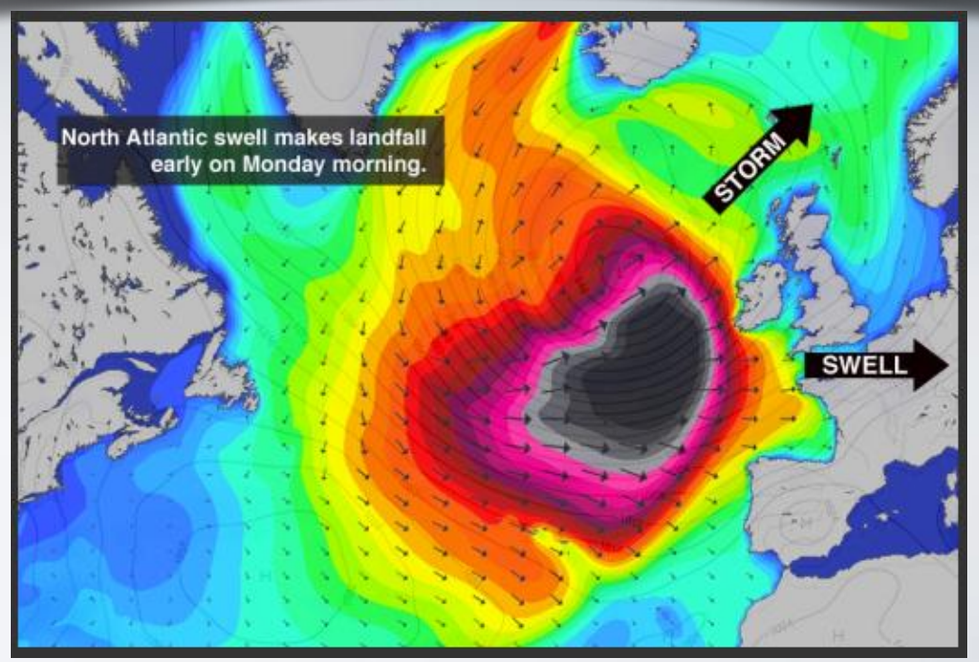
Motivation & Introduction

Irish **Atlantic Coast** & the Harsh Environment

Photo: Sean Curtin

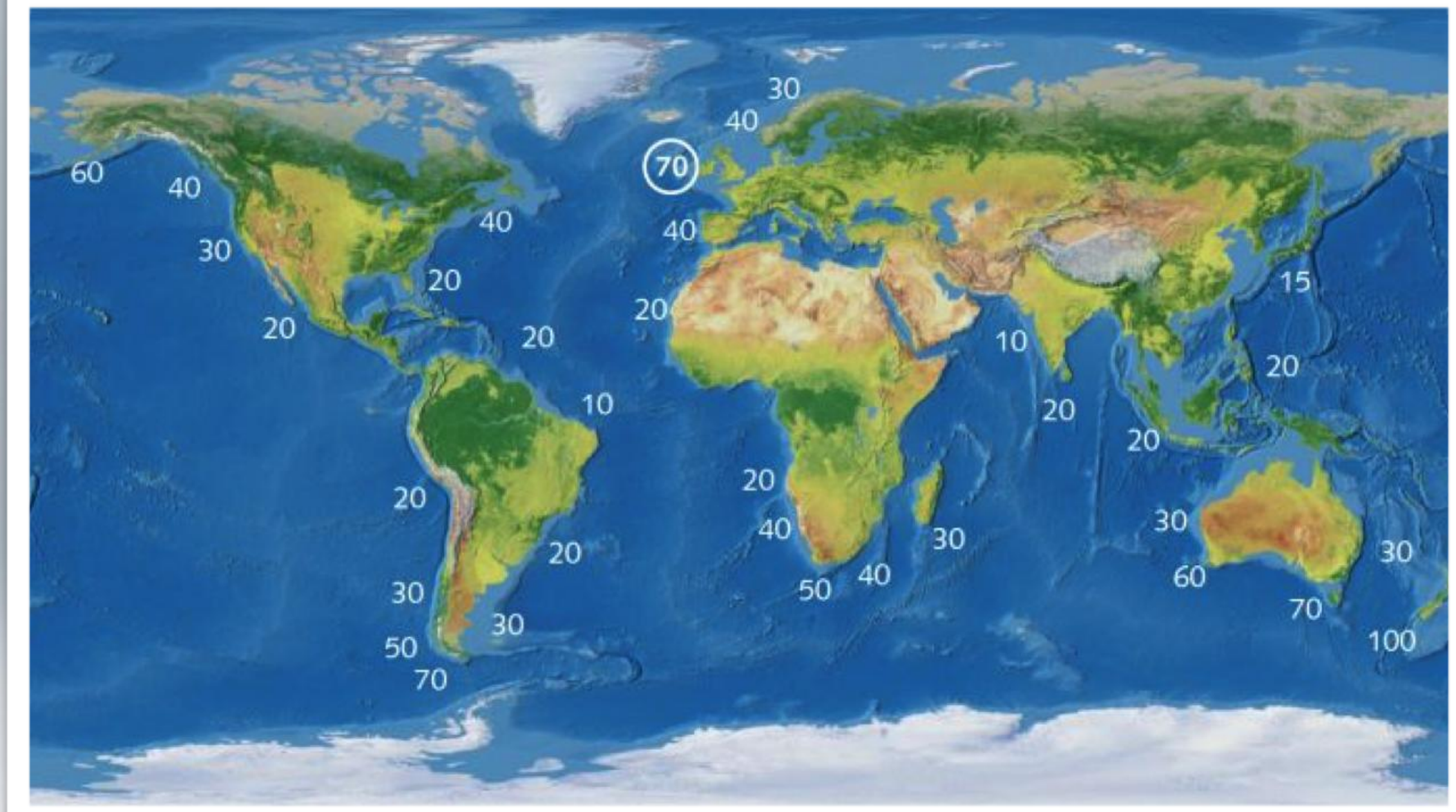
3rd of January 2014. Photo: George Karbus

6th of January 2014. Photo: Sarah Gallagher



Wave Forecast for 6th of January 2014. Source: www.magicseaweed.com

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**?

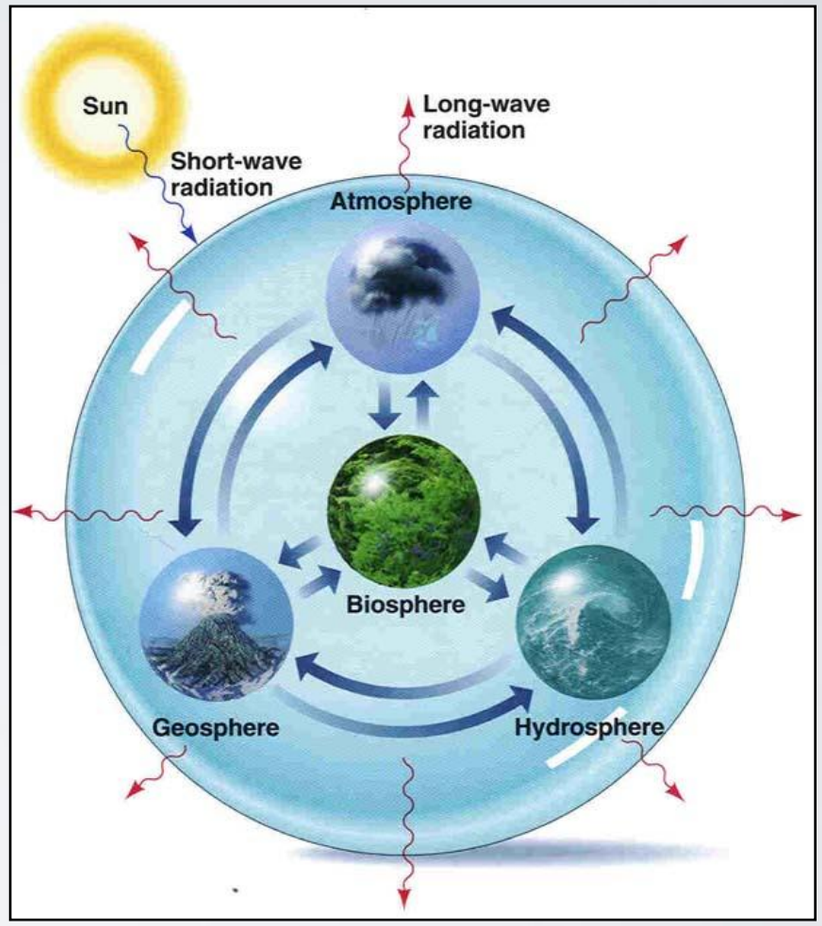
Figure: Left panel: an artist's impression of an array of the Oyster® Oscillating Wave Surge Converter (OWSC), developed by Aquamarine Power Ltd. Right panel: the Oyster 800 wave energy converter at the European Marine Energy Centre (EMEC) in Orkney. *Image courtesy of* `http://www.aquamarinepower.com`.

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

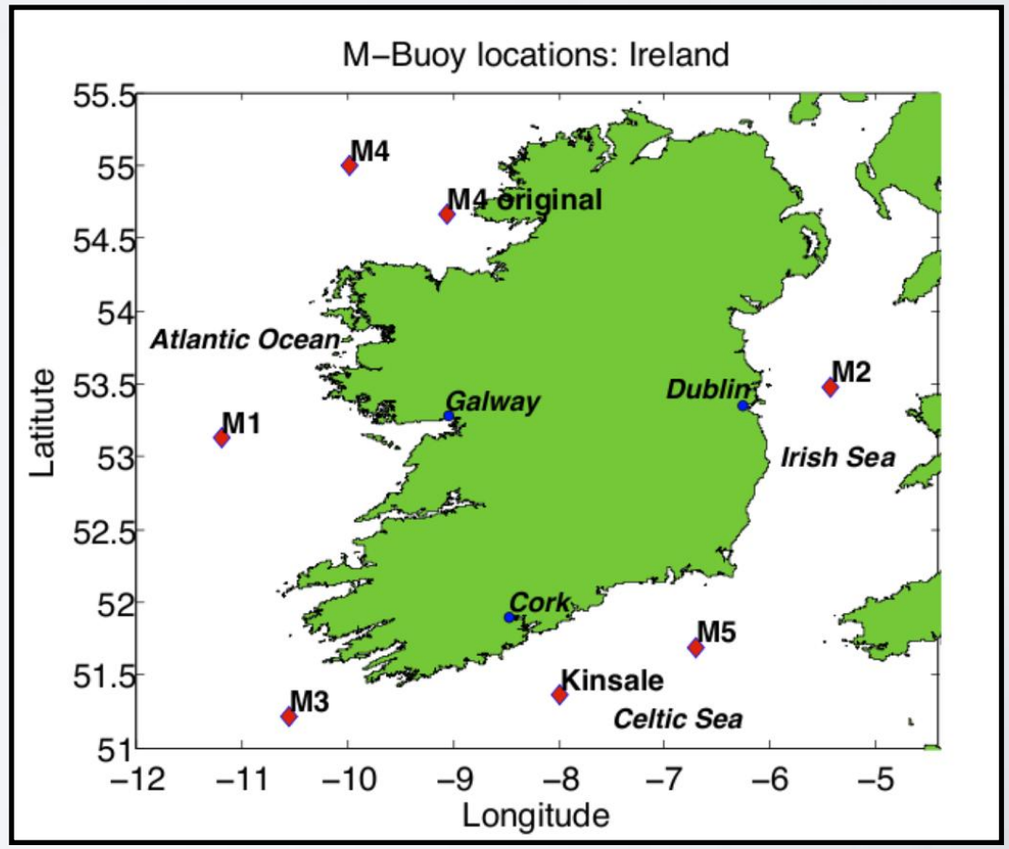
- Wave climate is the averaged condition of the waves over a period of years -- shown by parameters such as **wave height, period, direction**



Source: 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)



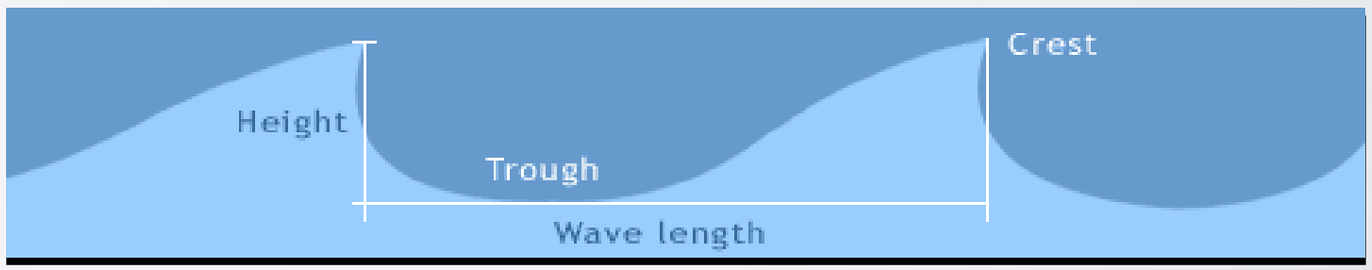
- Nearshore wave buoys (from 2008)
- **Satellite** wave data: since 1992 - low temporal resolution

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)

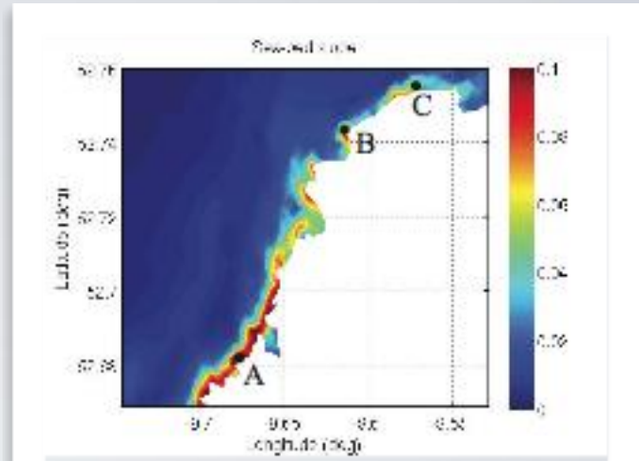
Source: http://en.wikipedia.org/wiki/Atlantic_Ocean



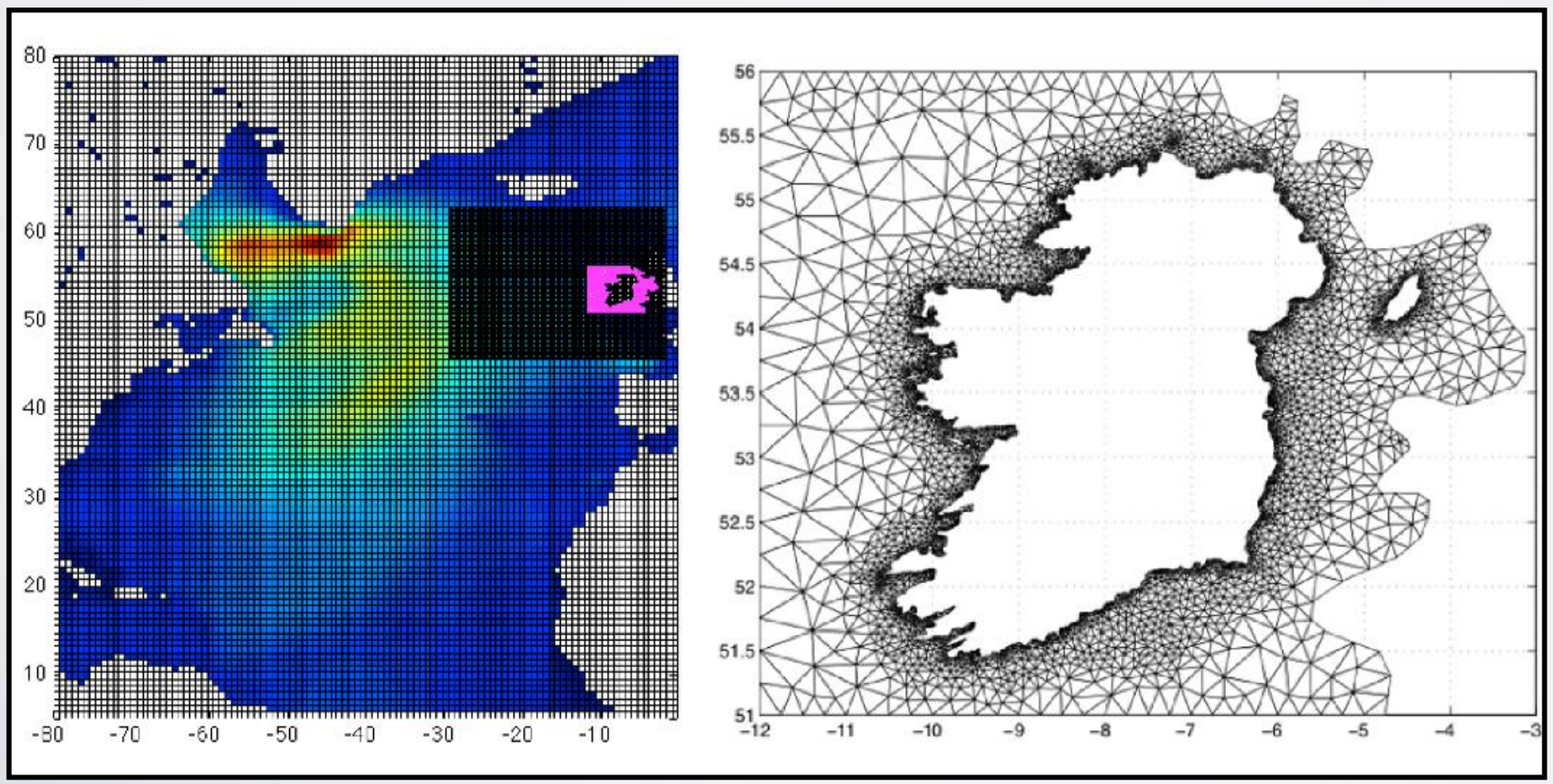
Source: http://www.ecy.wa.gov/programs/sea/coast/waves/big_waves.html

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)

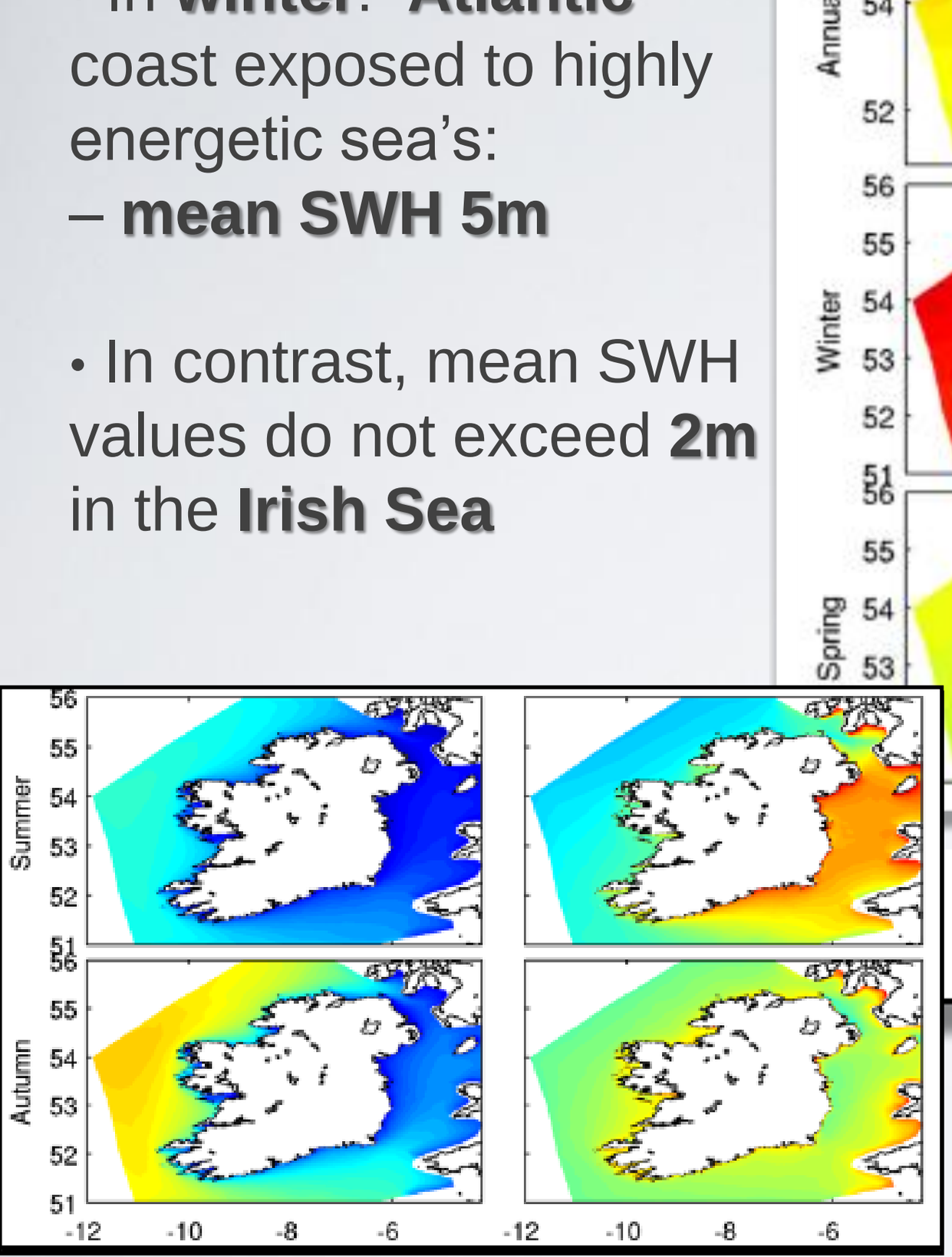


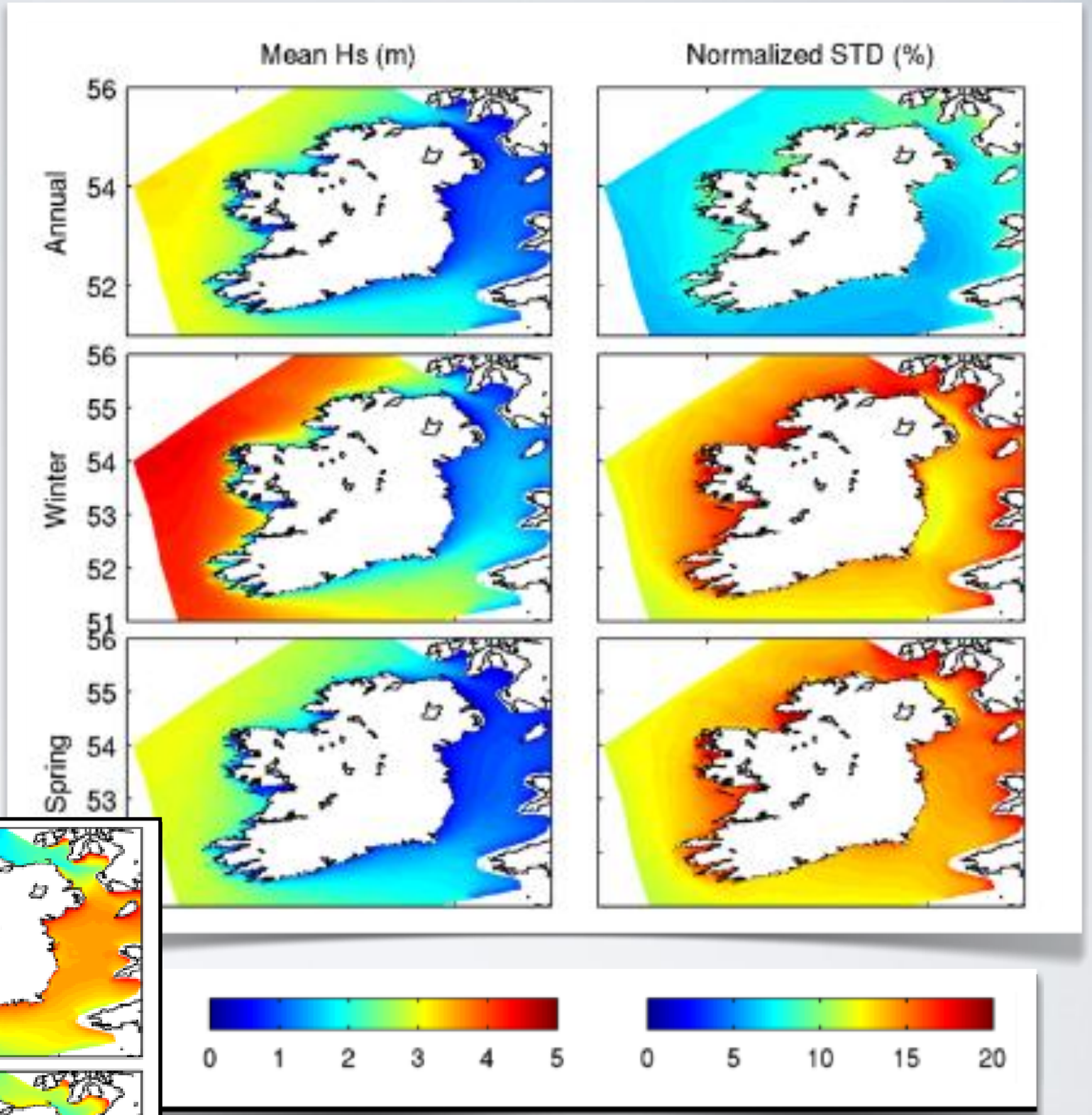
Present Wave Climate of Ireland

WAVE HEIGHTS

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

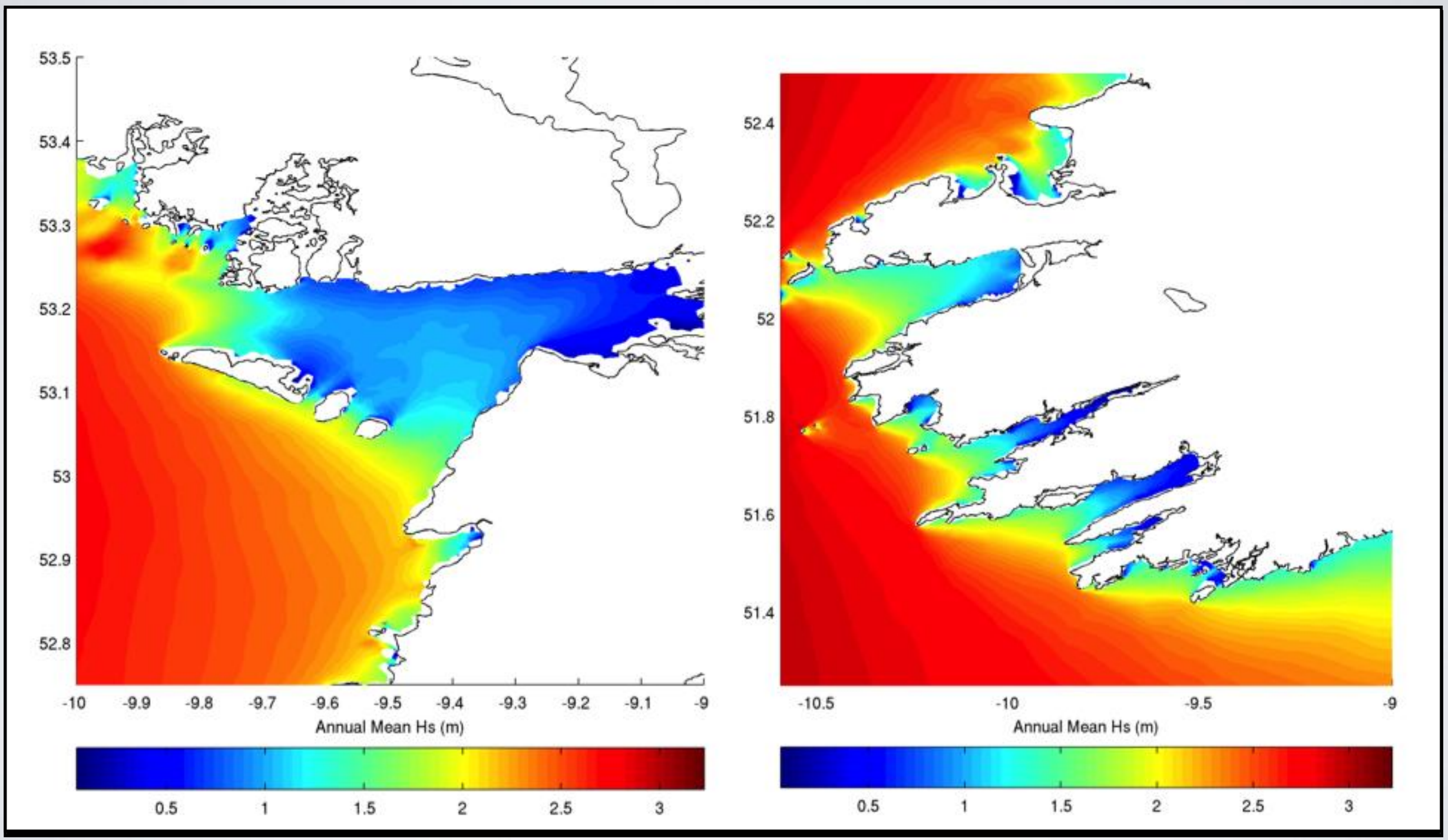
- In contrast, mean SWH values do not exceed **2m** in the **Irish Sea**



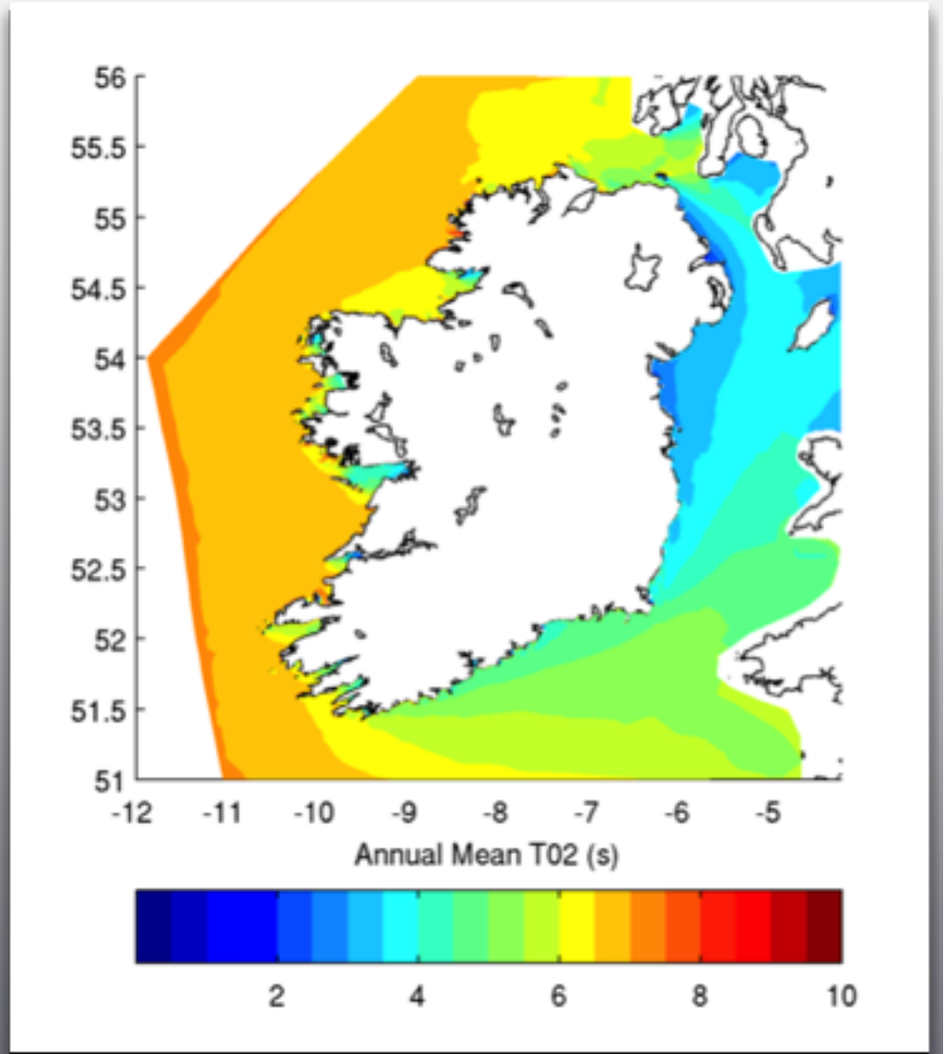


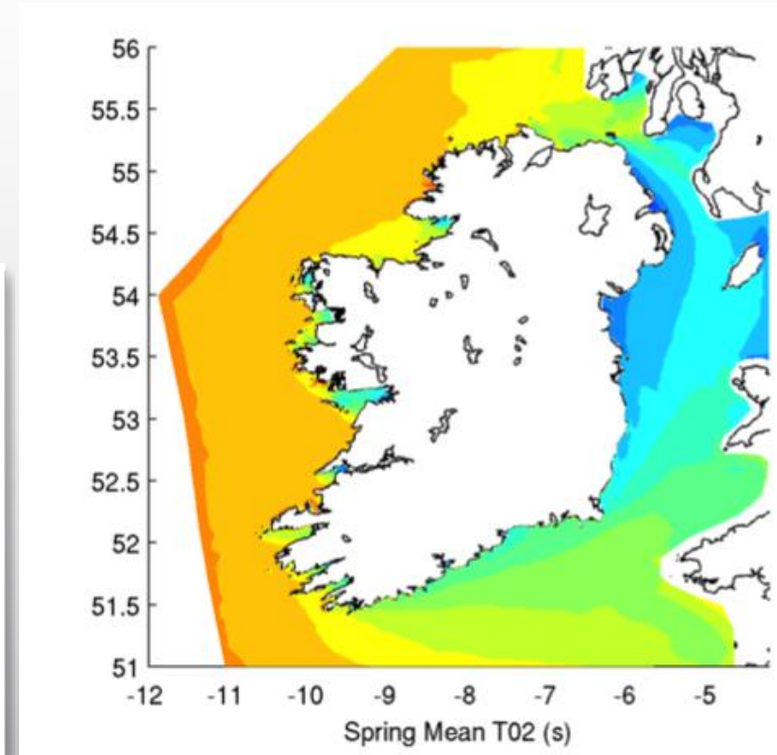
- Large inter-annual **variability**:
  - up to **10%** for **annual** means
  - over **20%** in **winter** & **spring**

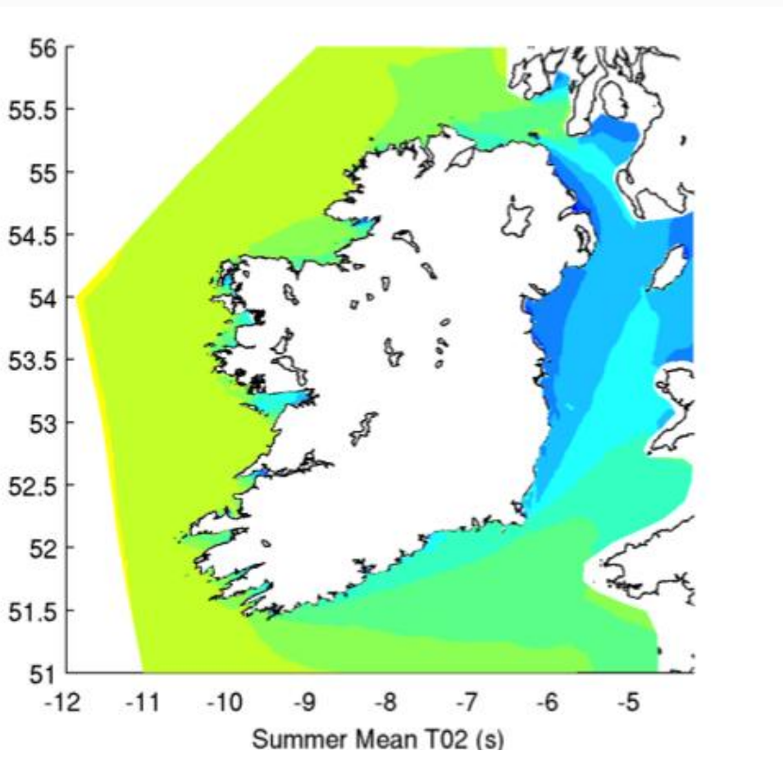
WAVE HEIGHTS - A **regional** close up!

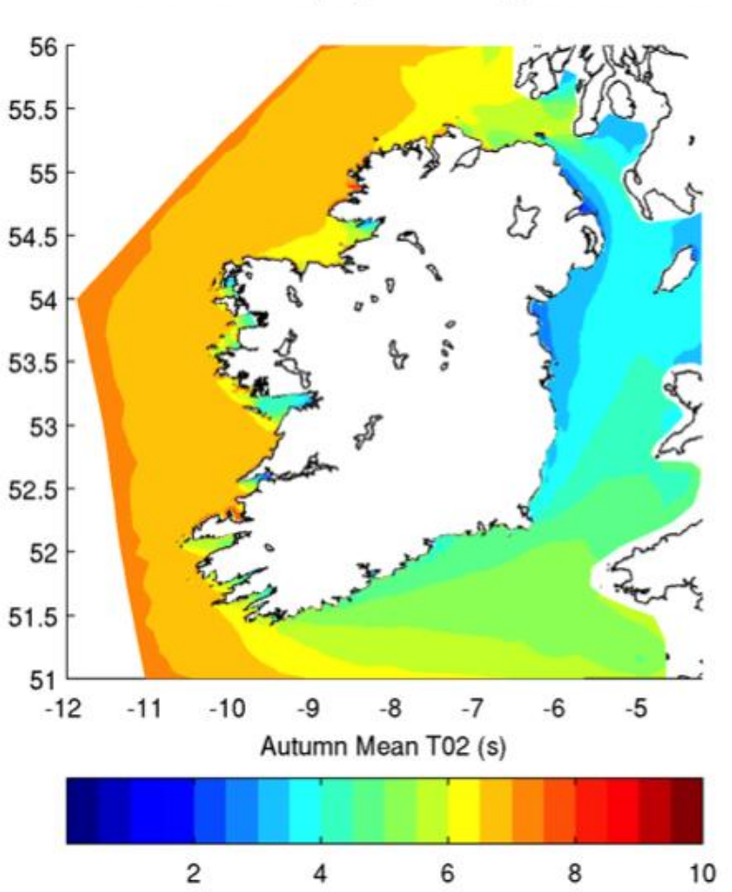


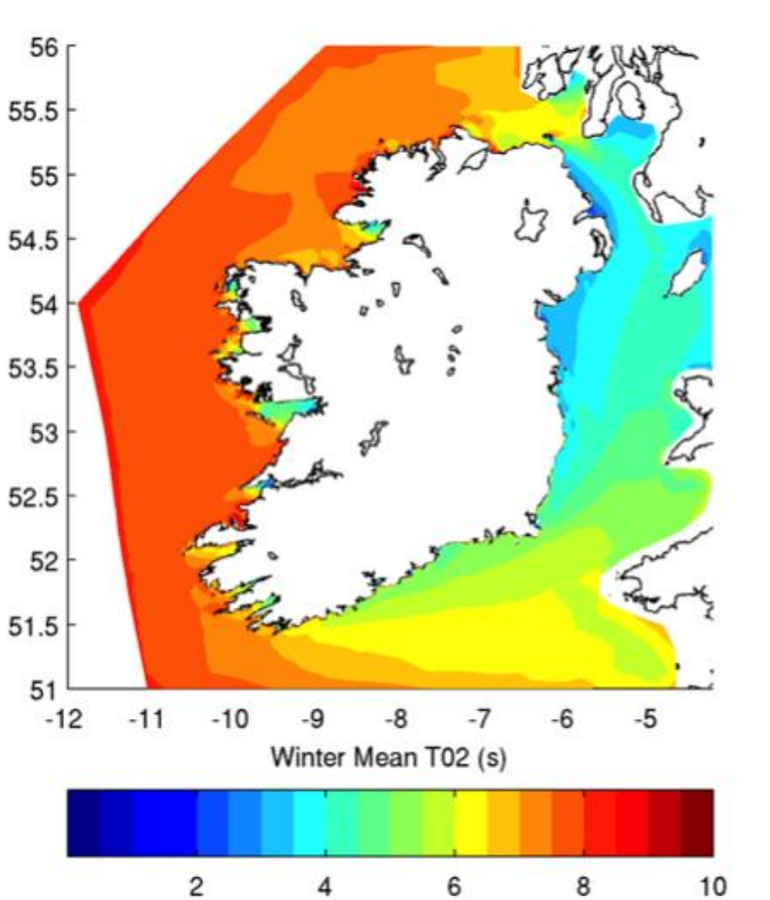
WAVE PERIODS



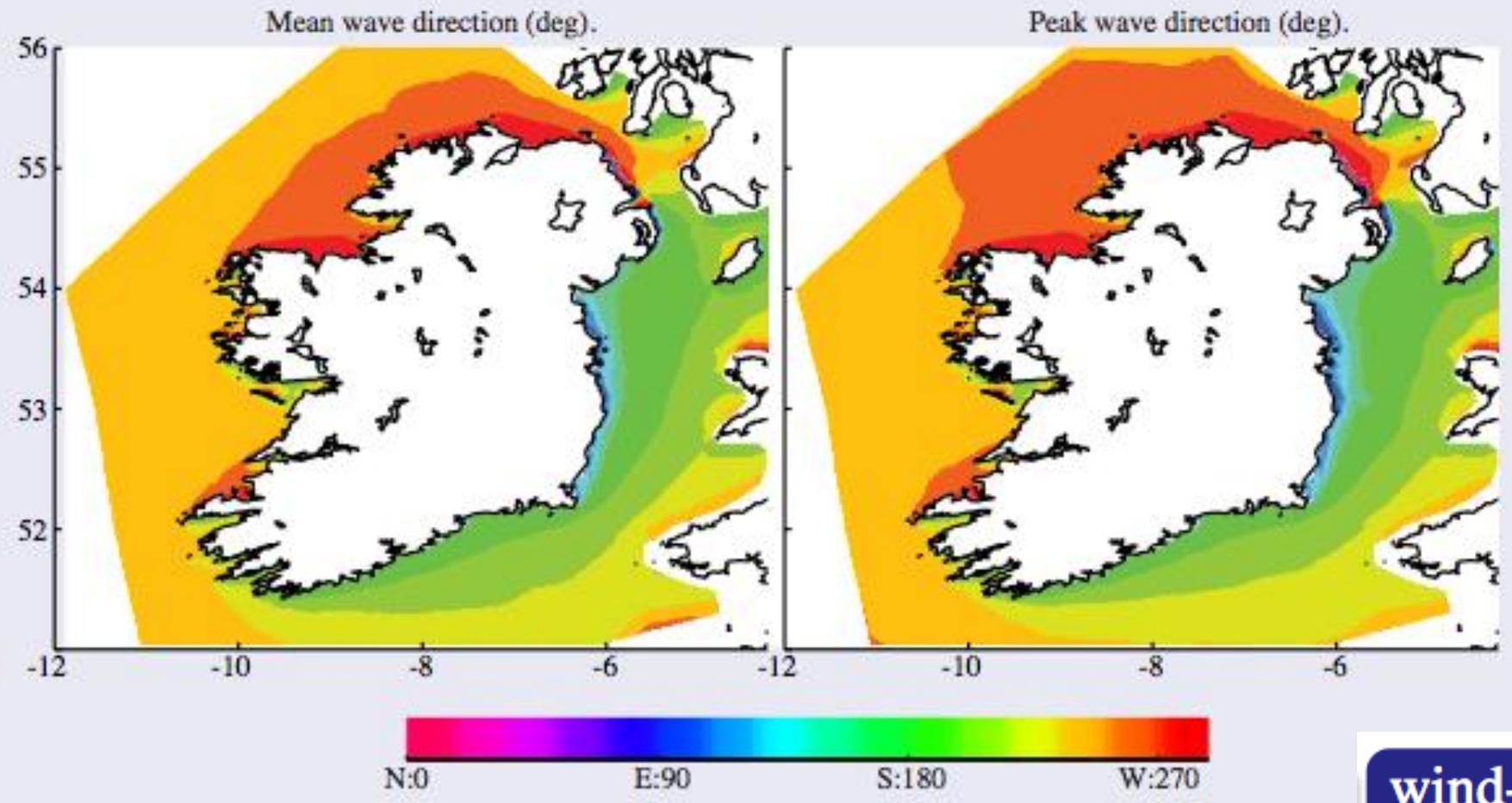






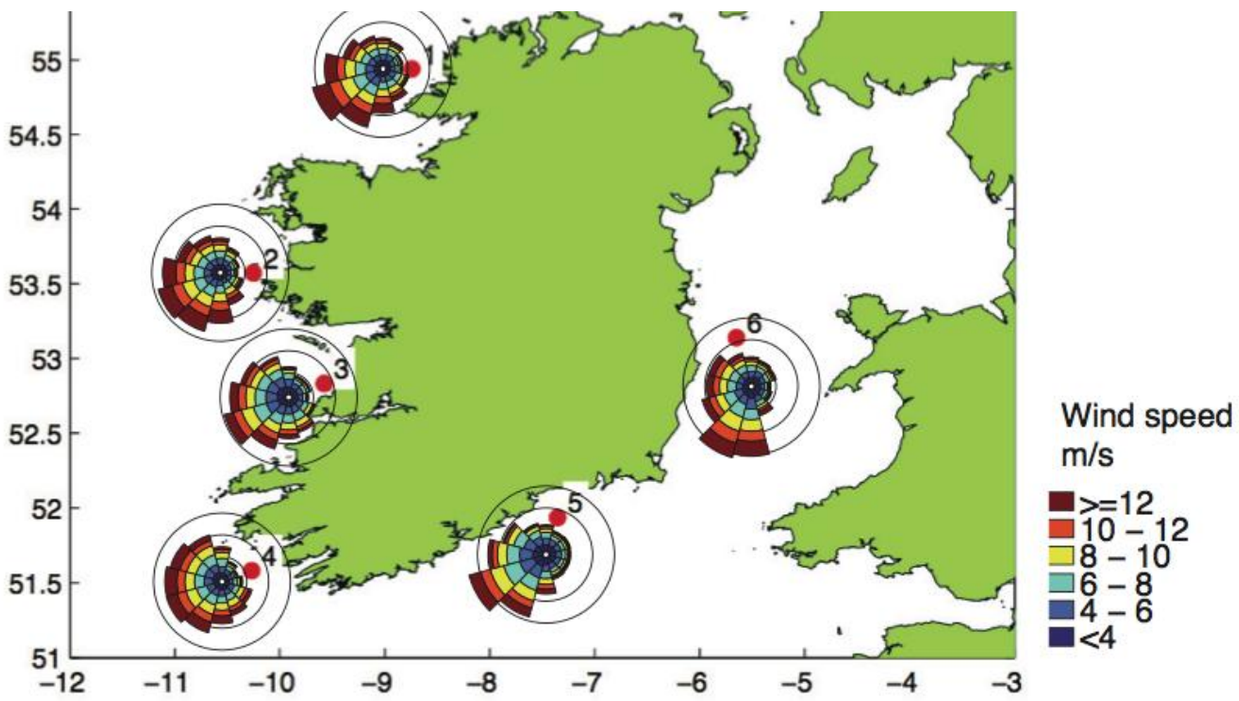


wave direction

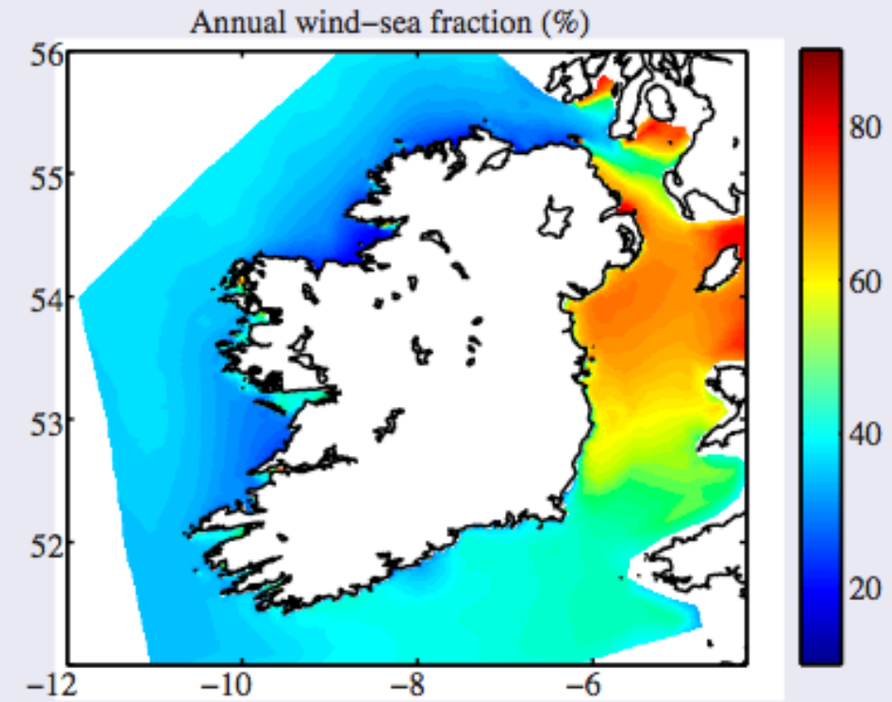


Gallagher et al. "A long-term nearshore wave hindcast for Ireland: Atlantic and Irish Sea coasts (1979–2012)."

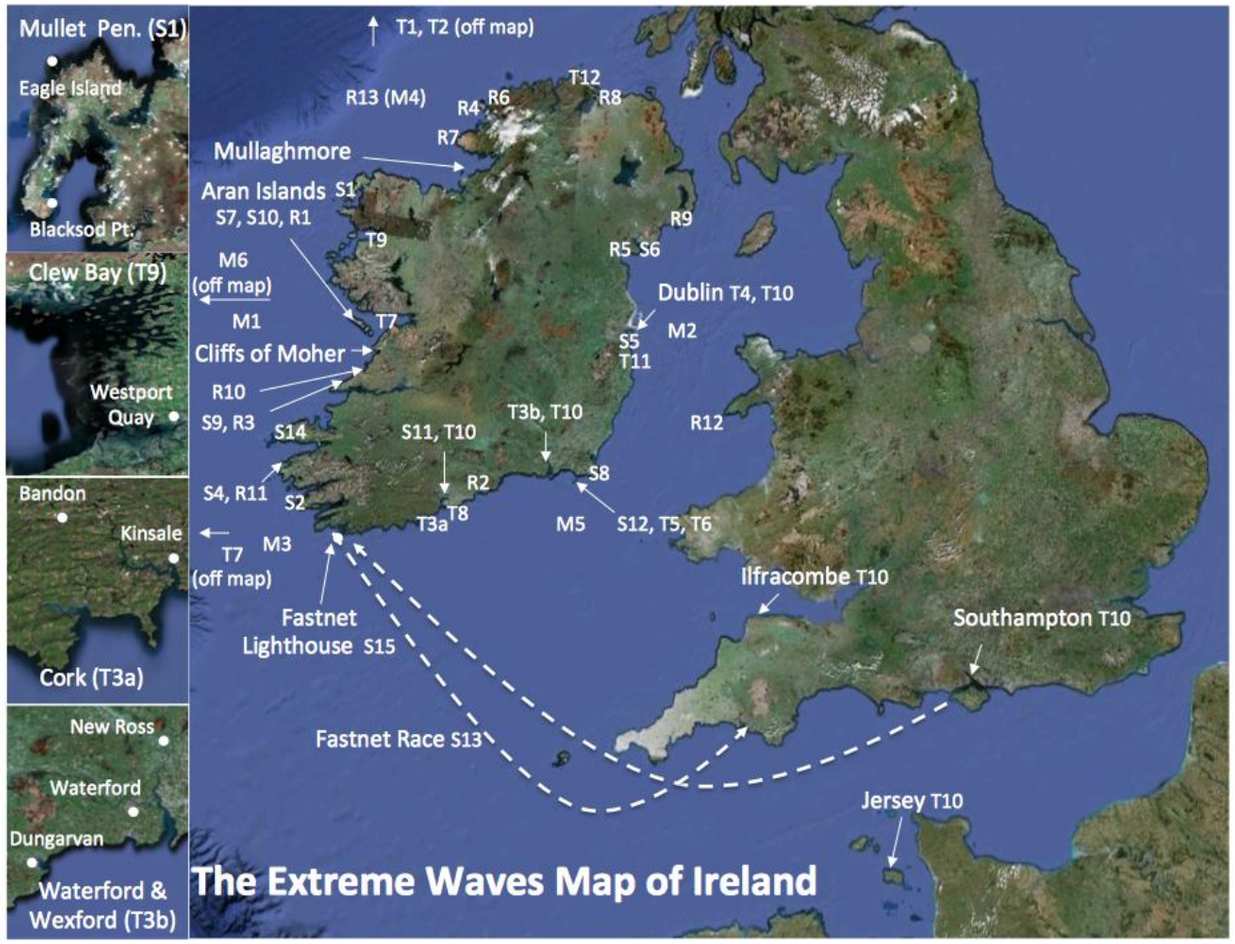
Ocean Dynamics, 64(8):1163–1180, 2014



wind-sea fraction

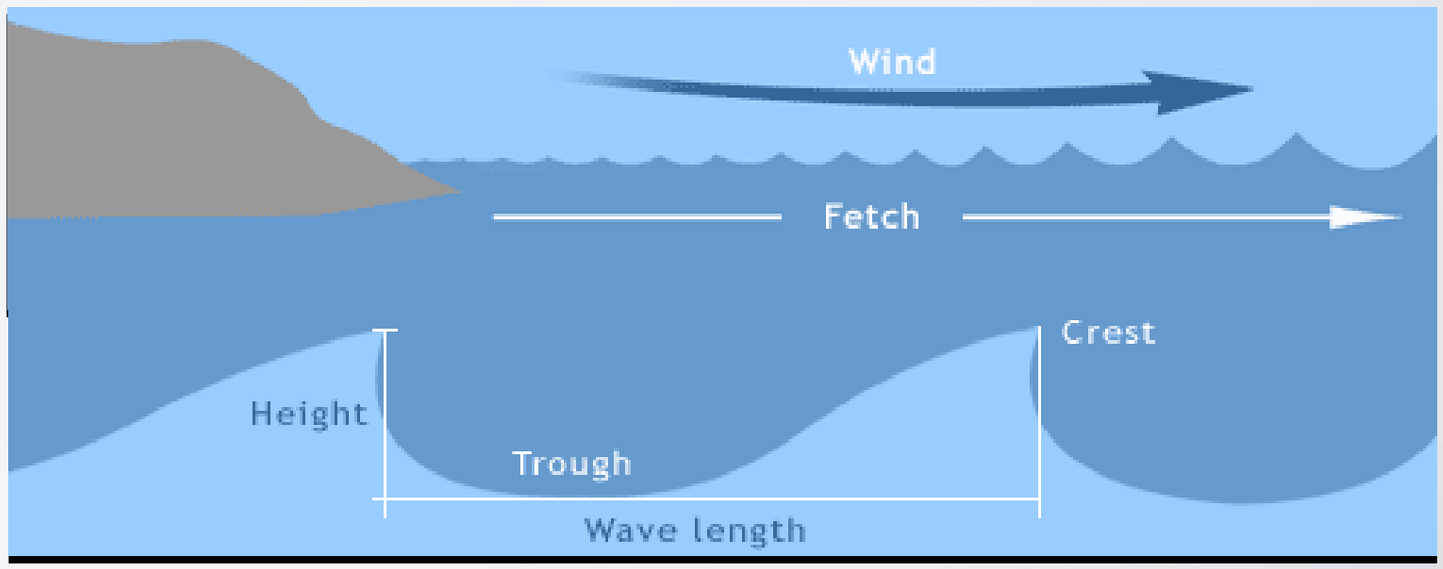


Irish Wave Climate



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

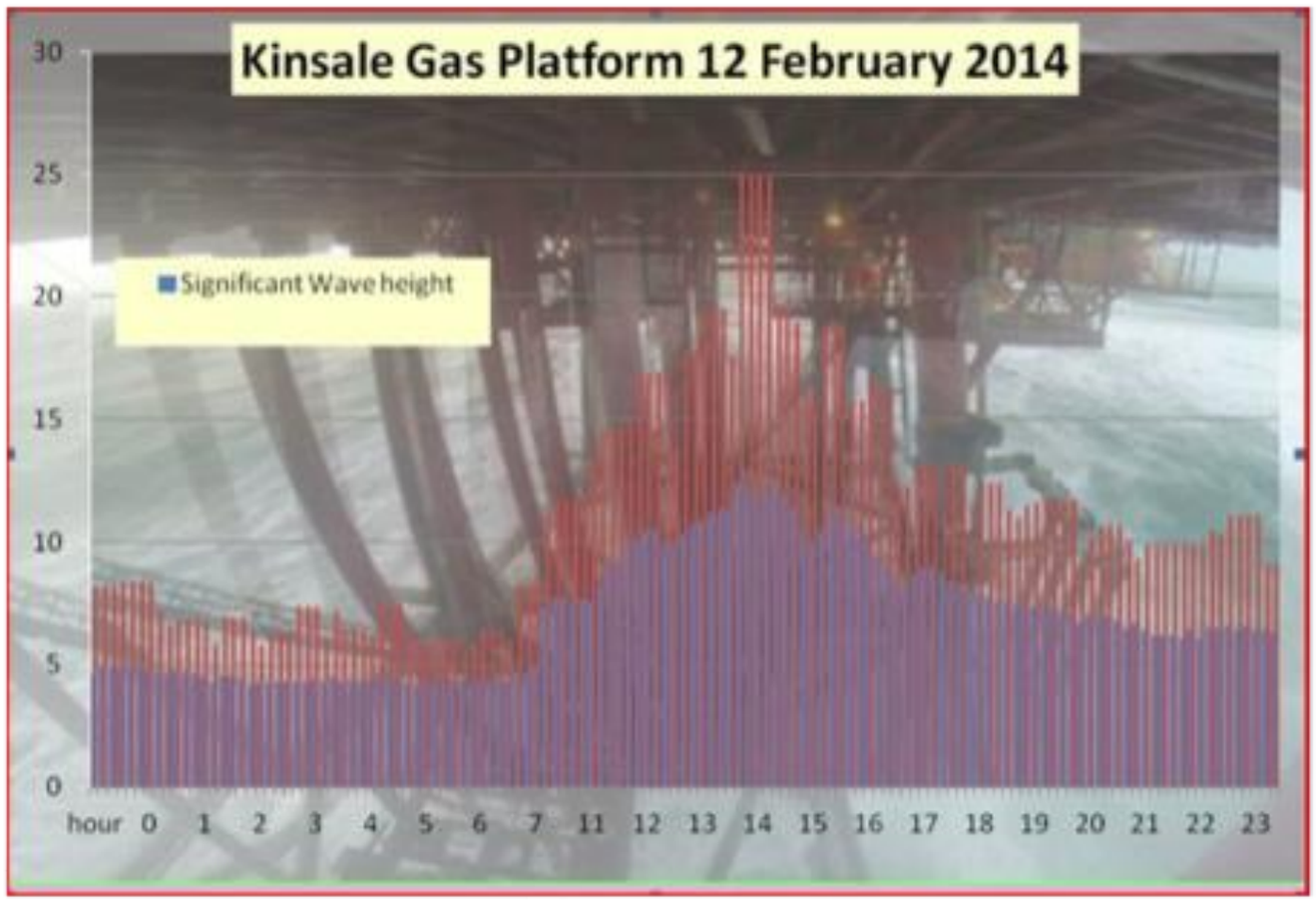
O'Brien et al. "Extreme wave events in Ireland: 14 680 BP-2012", Nat. Hazards Earth Syst. Sci., 13, 625-648, 2013

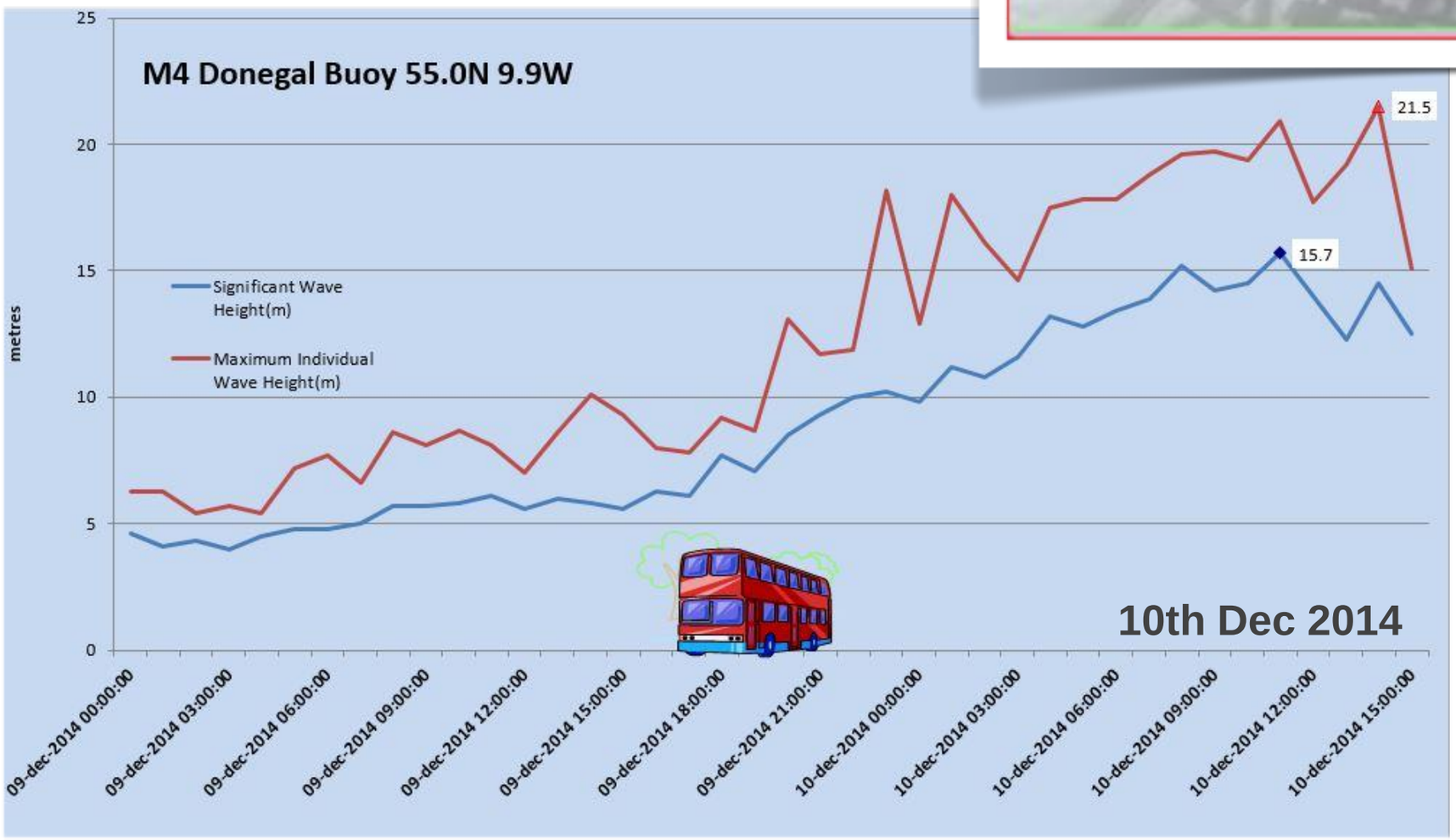


Source: http://www.ecy.wa.gov/programs/sea/coast/waves/big_waves.html

OBSERVATIONAL RECORD

- **Largest wave** recorded on the12th Feb 2014 at the Kinsale Energy Gas Platform: **25m individual wave** in a Significant Wave Height* of **12m**



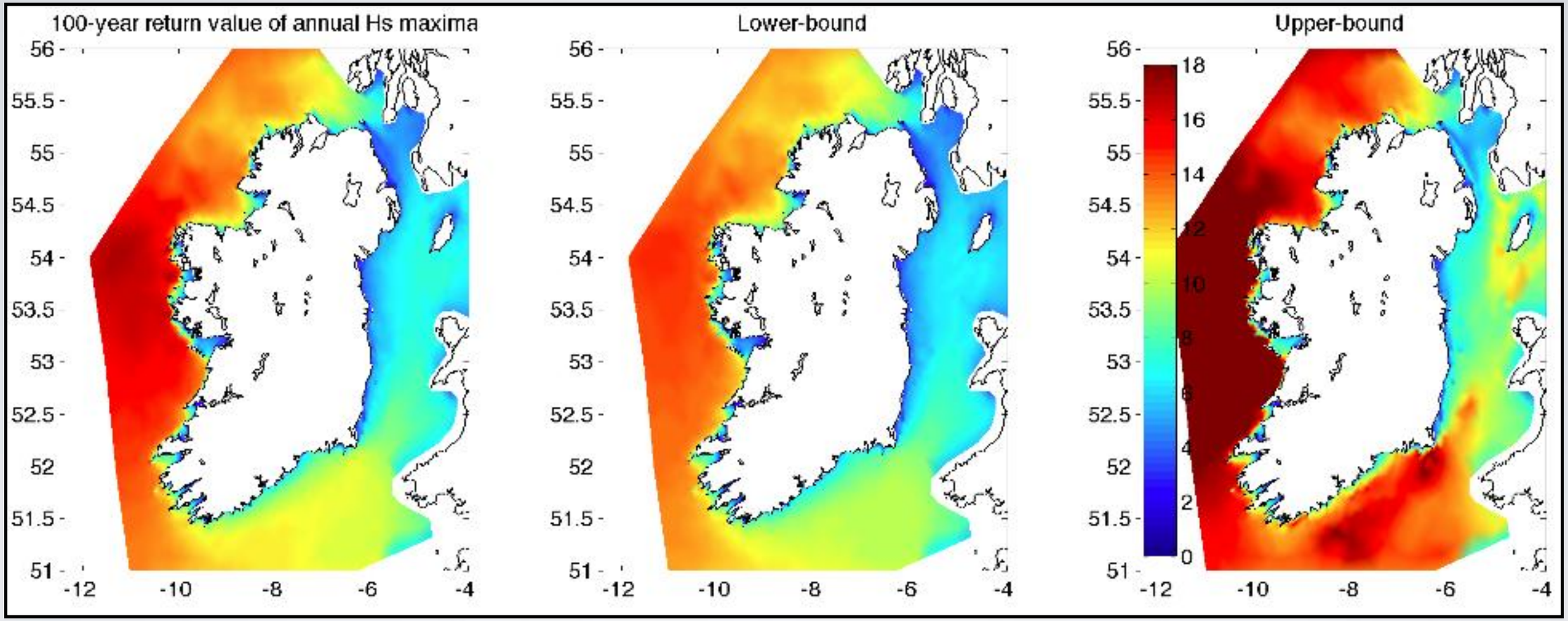


*Significant Wave Height (**SWH**) = mean wave height (trough to crest) of the highest third of the waves

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

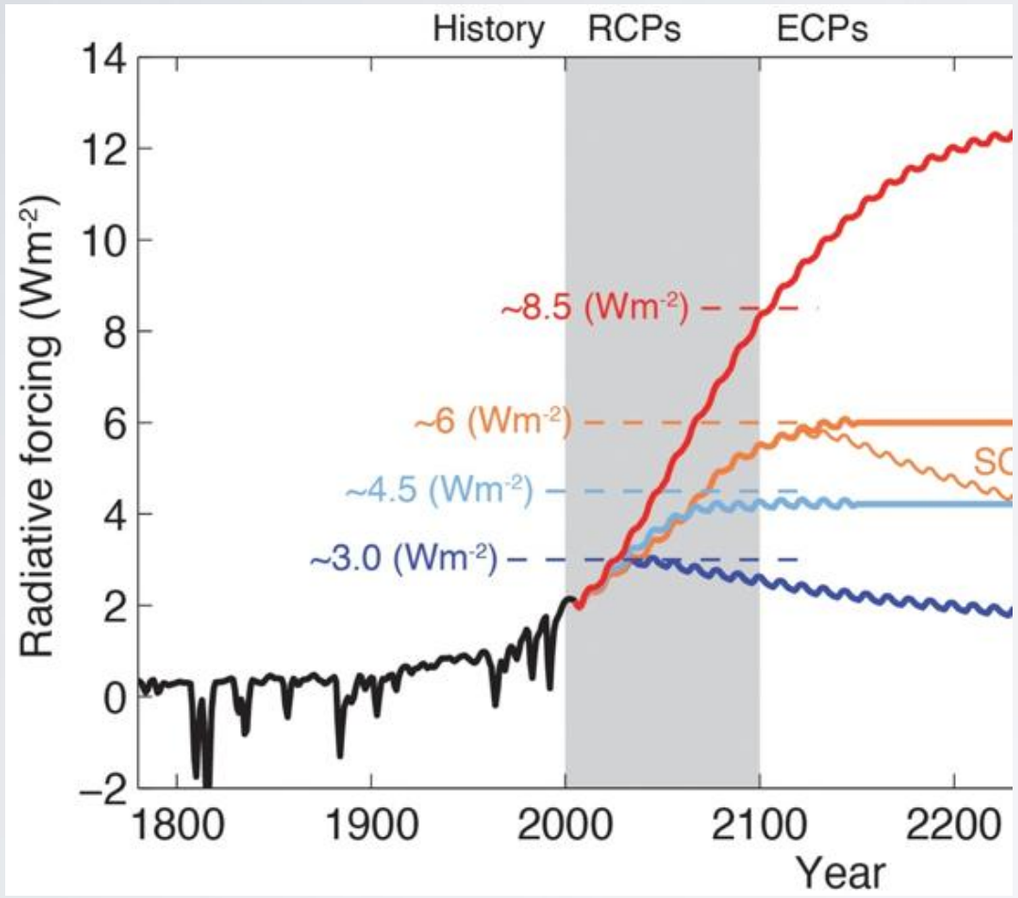
- Centre & right panels: lower & upper confidence bounds of the return period at the 95% confidence interval level

The WMO defines **SWH >14m** as a ***PHENOMENAL*** sea-state!

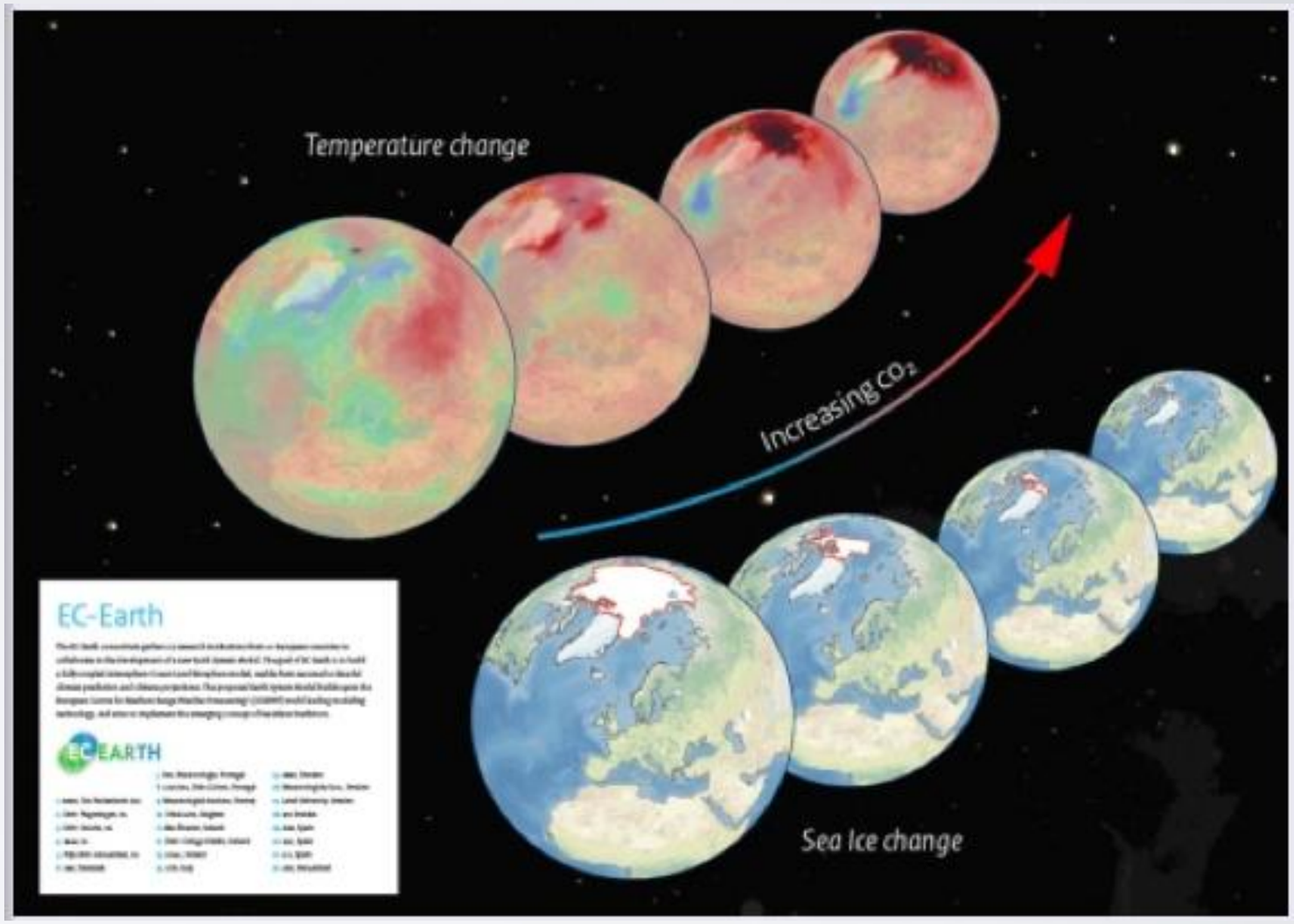
Future Wave Climate of Ireland

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)]*

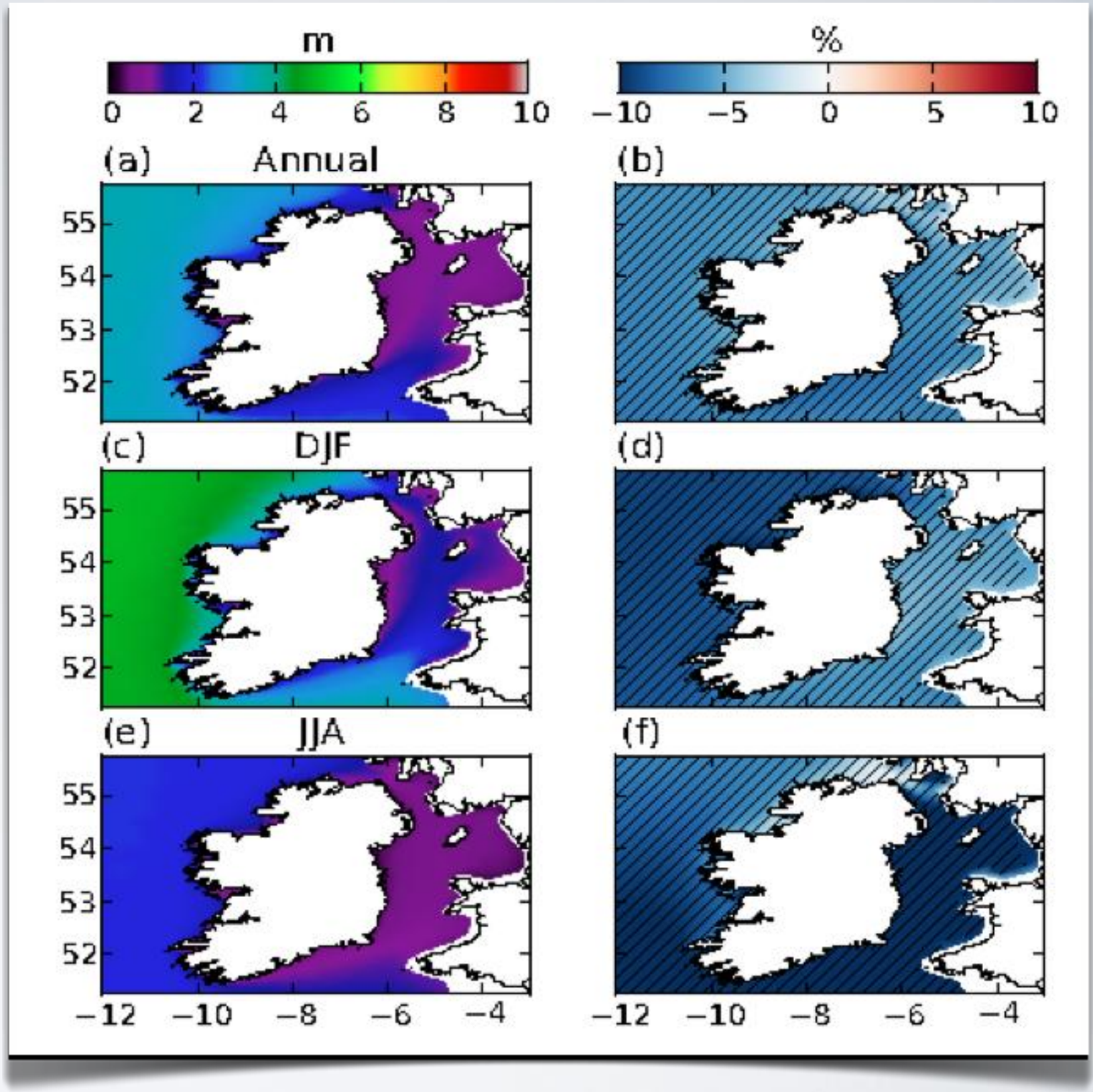
- **RCP4.5** & **RCP8.5** 10m **winds** & **ice-fields** to drive **wave model**
- Time period **1980-2009** vs. **2070-2099** (30-year averages)

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)



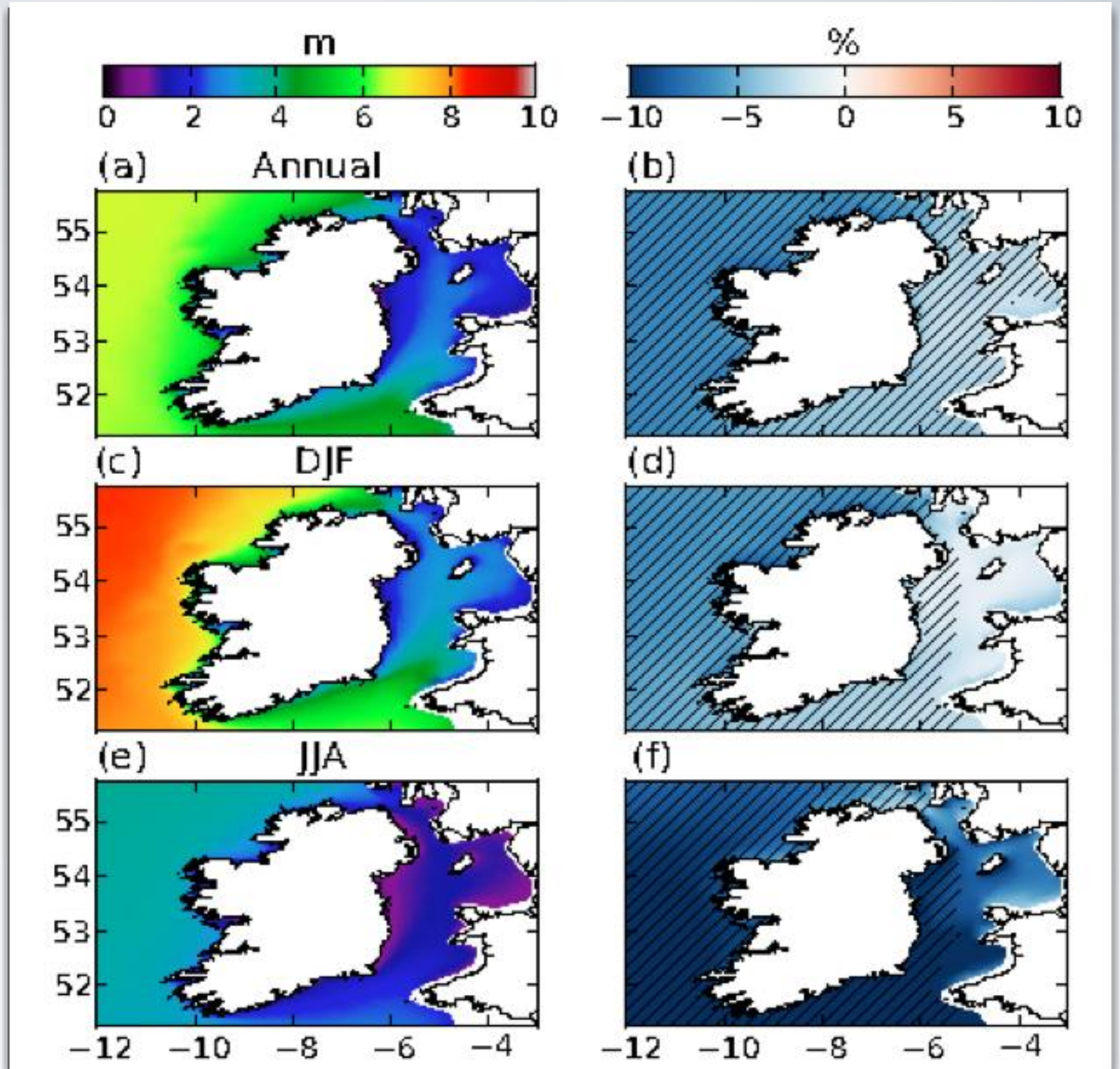
Hatching: where the magnitude of wave model ensemble difference exceeds twice the inter-model standard deviation

WAVE **Extremes**

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

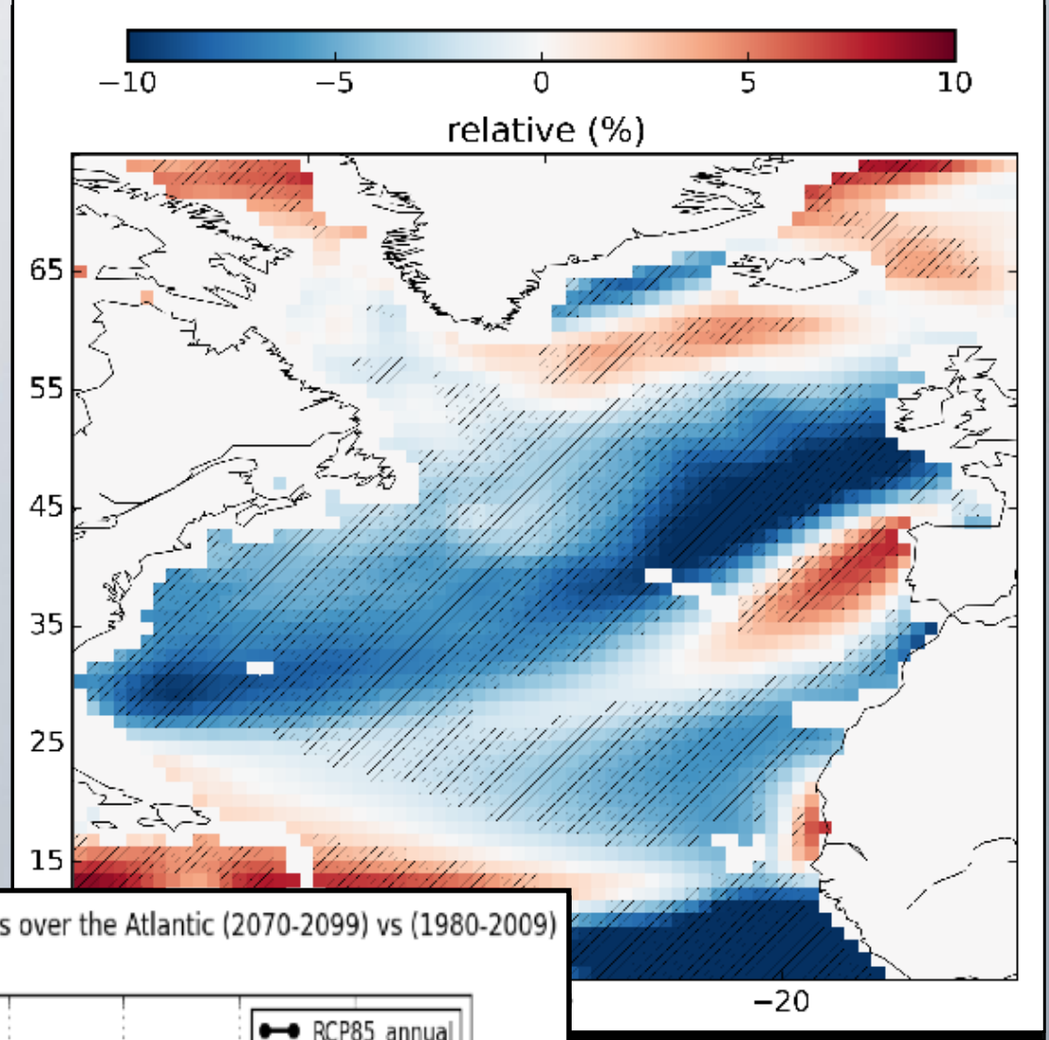
- Left panels: Averaged historical multi-model **annual** (a), **winter** (c) & **summer** (e) 95th-percentile of SWH (m) (1980–2009)

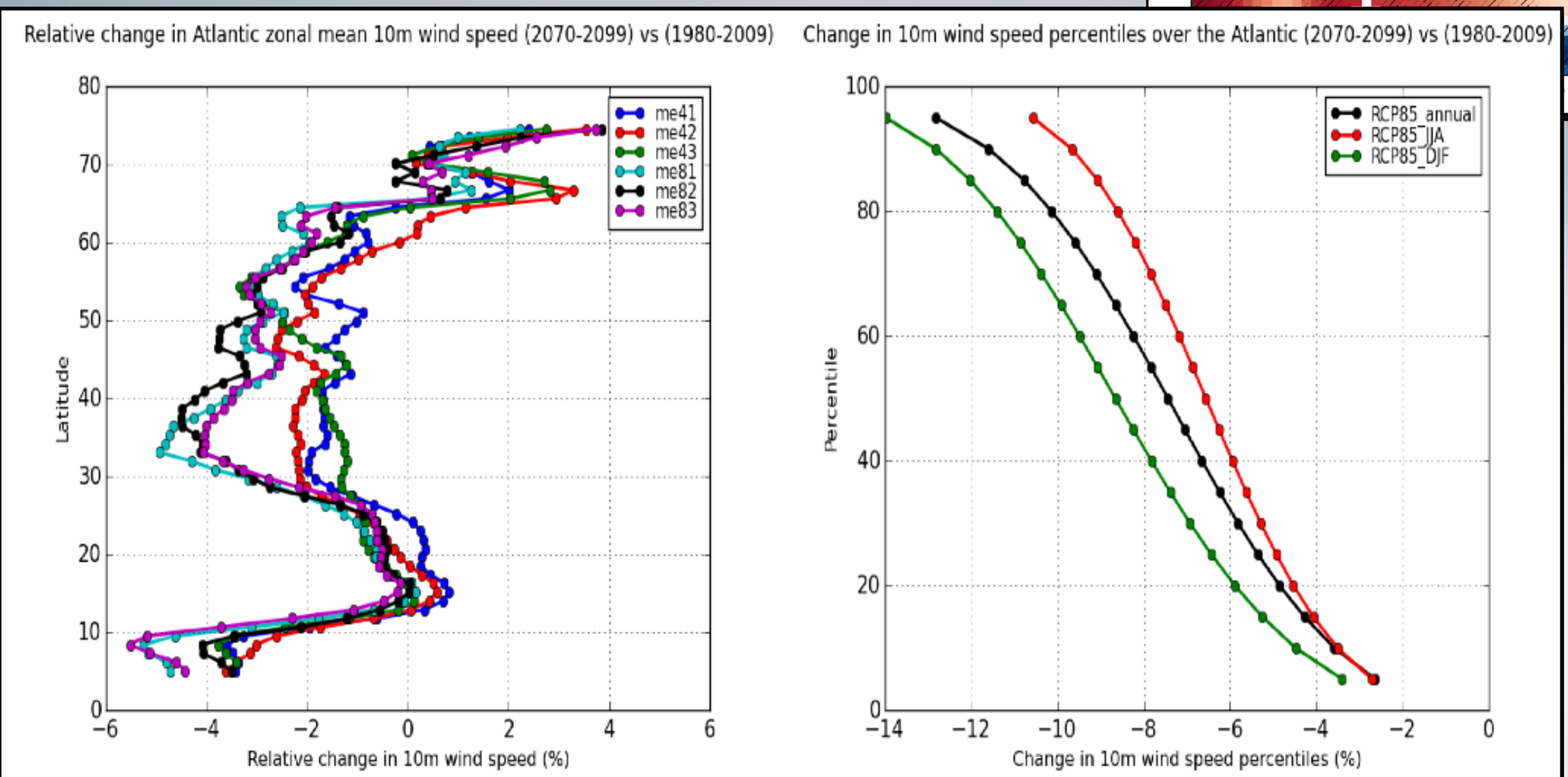
- Right panels: averaged wave model ensemble **projected changes** in **SWH (m)** for **RCP8.5** (2070–2099)



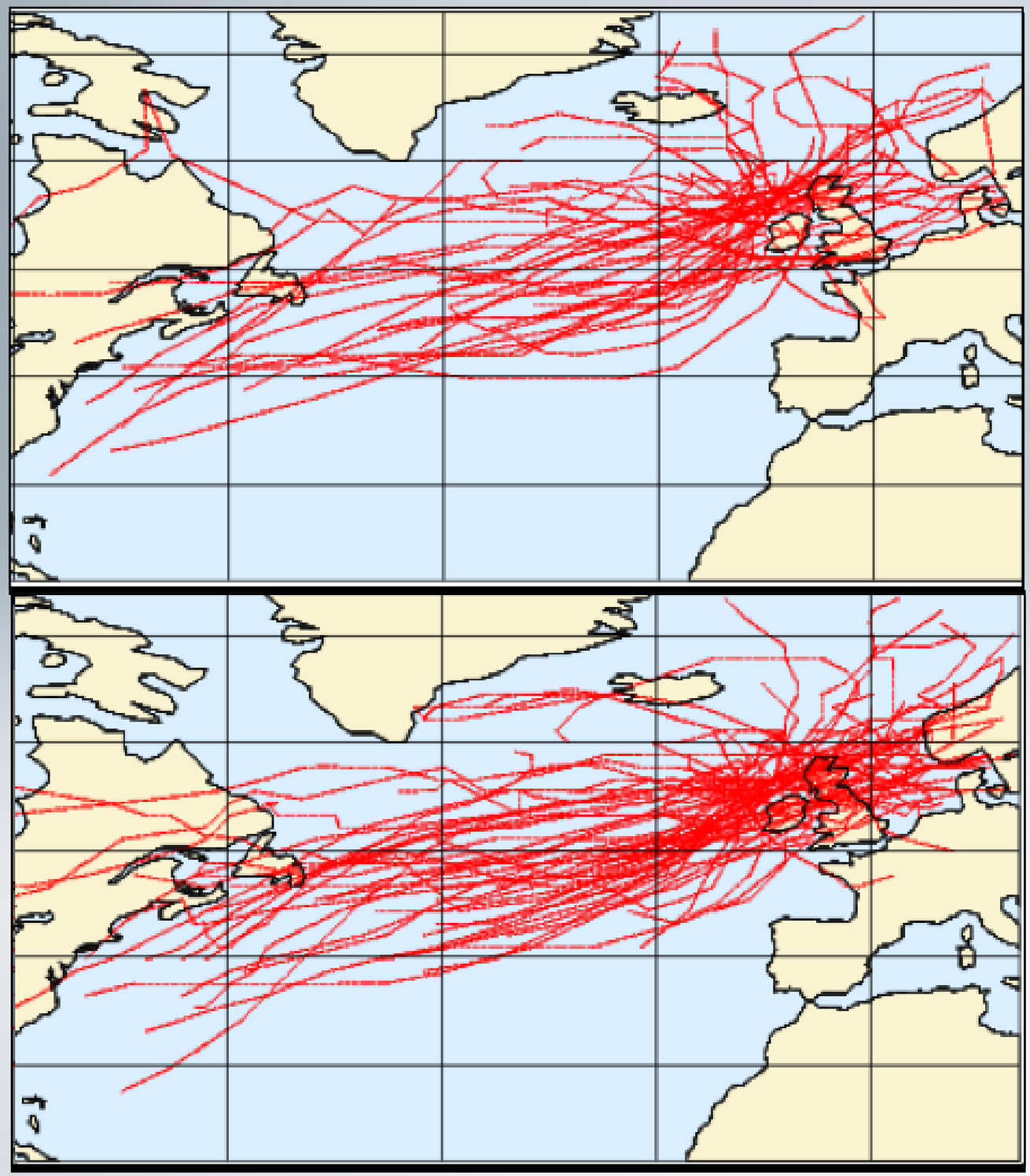
Hatching: where the magnitude of wave model ensemble difference exceeds twice the inter-model standard deviation

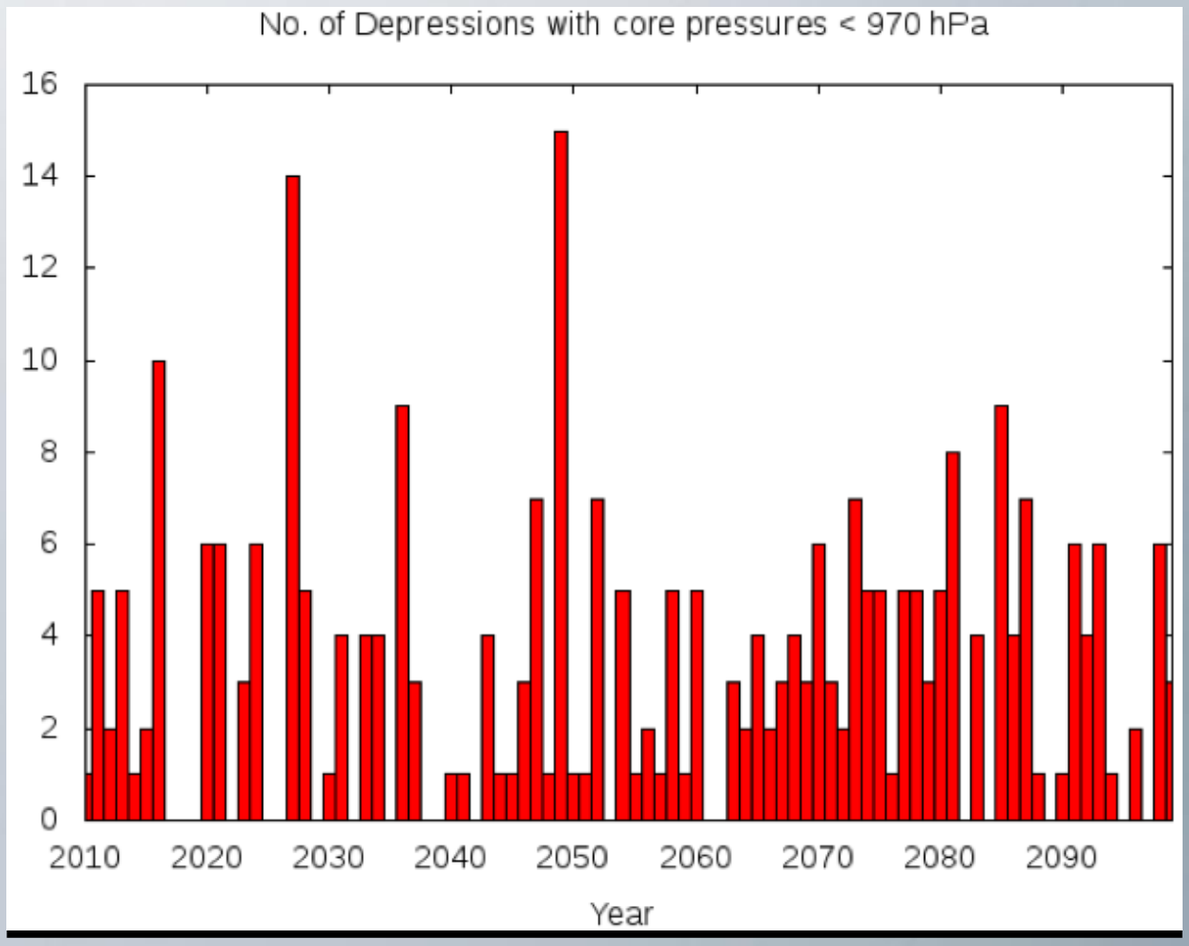
Can this decrease be **linked** to North Atlantic winds?





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**

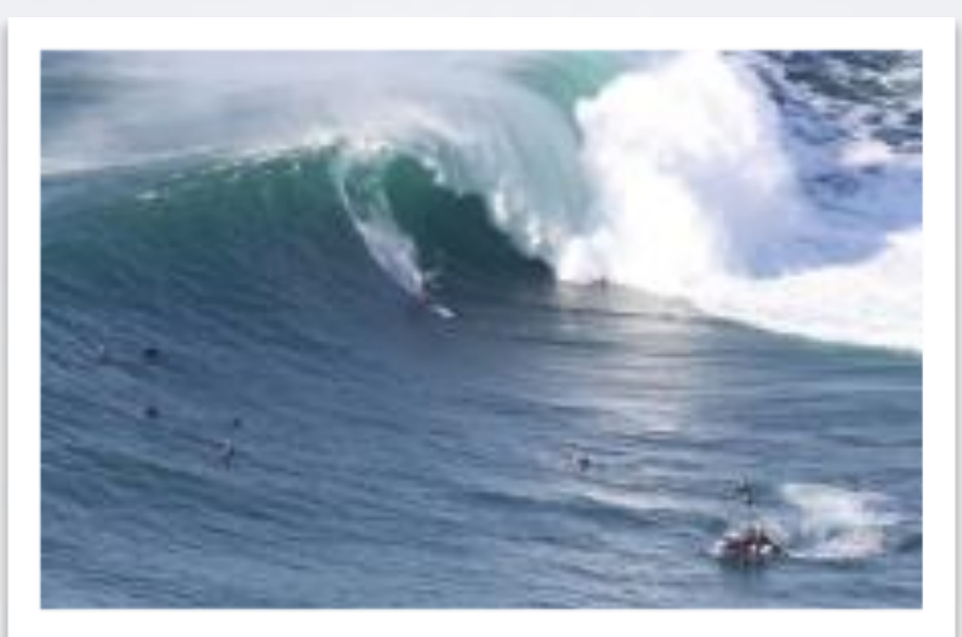
Thank you for listening…

Any **Questions?**

Acknowlegements

- Columba Creamer, Emily Gleeson, Ray McGrath, Eoin Whelan, Met Éireann

- Frédéric Dias & Roxana Tiron, UCD



Aileen's wave at the Cliffs of Moher, Co. Clare