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The future wave climate of Ireland: from averages to extremes

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Abstract

In this study we examine a likely future wave climate projection for Ireland using the Representative Concentration Pathways (RCP) 4.5 climate scenario for the years 2031-2060. Global EC-Earth 10m winds are used to drive a basin scale wave model (North Atlantic) with two higher resolution nested grids zooming in on Ireland. The changes in the future wave climate are assessed by comparison to a 30-year high-resolution hindcast that targets the present wave climate. An overall decrease in the significant wave heights was found around Ireland, with a maximum decrease in the winter mean reaching over 20cm. An increased storminess in winter and spring was found in the north and northwest.

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1. Introduction

Given the considerable socio-economical importance of the sea for an island nation such as Ireland (for fisheries, shipping and other marine industries, the potential for renewable energy exploitation but also recreation and tourism), it is important to know: How will climate change affect the wave climate of Ireland? Will Ireland be exposed to higher or lower wave heights in the future? Will there be an increase or decrease in storm activity? Could this enhance coastal erosion and coastal hazards?

Due to its location in the Northeast Atlantic, Ireland possesses one of the most energetic wave climates in the world. The recent review of O'Brien *et al.*[6] has revealed a long history of large waves around Ireland from large storm waves to the more elusive but yet destructive freak waves. The former can be linked to the prevalent strong winds in Ireland (from 1961 to 1990 the mean number of days with gales at Malin Head was 66[6]). The latter have only recently been accepted as a distinct wave class, and can loosely be defined as large and highly powerful waves, that seem to appear from nowhere, with heights 2-3 times larger than the surrounding sea-state[4]. They also have

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short ‘life-spans’ and are localized in space, which makes them notoriously hard to predict. And yet, it is truly remarkable that with very few buoys and in a relatively short time interval (of about 10 years) massive waves have in fact been measured in Irish waters. On the 13 December 2011 the M4 buoy located 75km off the Belmullet peninsula (see Figure 1) registered a 20.4m wave in a sea-state with wave heights of about 13m.

A natural question arises: can a wave-forecasting model capture such formidable waves? Wave forecasting is an area that has experienced tremendous progress in recent decades[1]. This has been spurred on by both improvements in understanding of the underlying physical processes that govern wave generation and propagation, but also by the ever-increasing mass of observations at a global scale (including satellite measurements), observations which allow thorough validation and calibration of the models. Nonetheless, a key limitation is the dramatic disparity between the scales these models need to address (ocean basins – thousands of kilometres in span) and the scale of the waves themselves (tens of metres). Due to this disparity, wave forecasting models cannot afford to predict individual waves - rather they target the evolution of the sea-state, which in a sense represents the average/statistics of the waves over a set time-frame (typically 30 minutes). There is an on-going effort in the wave community to predict freak waves or steep storm waves (to find out how frequent they are, and what kind of meteorological conditions favour them) – but until a practical solution can be implemented, extreme waves remain largely ‘lost in the crowd’.

The most common measure of sea-states is given by the significant wave height, which in technical terms represents the mean wave height (trough to crest) of the highest third of the waves. This ratio is chosen because the significant wave height tends to be the height of the waves that is most readily observed by the human eye[9] but also (and perhaps more importantly), the larger waves are usually more significant than the smaller waves. As such, our study focuses on quantifying the spatial and temporal changes in the significant wave heights around Ireland that are expected to occur in the future. Our study reveals that even the significant wave height can frequently exceed 15m off the west coast of Ireland, implying that actual waves with heights over 20m trough-to-crest could be a common occurrence.

We examine a likely future wave climate projection for Ireland using the Representative Concentration Pathways (RCP) 4.5 climate scenario as defined by CMIP5 experiment design[7] for the years 2031-2060. The RCP 4.5 climate scenario predicts that the radiative forcing stabilizes at approximately 4.5 W/m^2 by 2100, compared to pre-industrial concentrations[5]. Global EC-Earth 10m winds (provided by Met Éireann) are used to drive a basin scale wave model (North Atlantic) in order to capture distant swells. These are then used to force two higher resolution nested grids zooming in on Ireland. The primary goal of our study is to examine what kind of changes in the wave climate Ireland can expect in the near future and contrast them to the present wave climate.

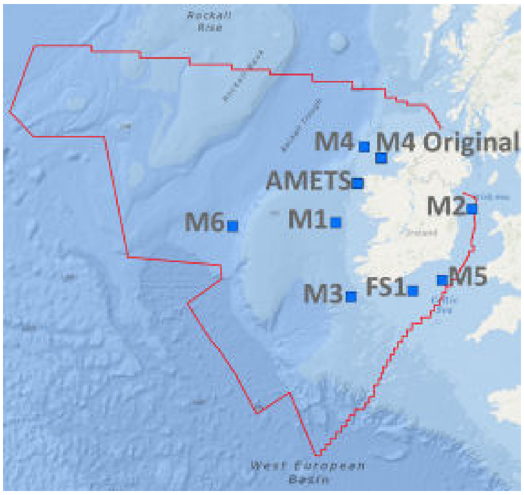

Fig. 1. Irish Moored Weather Buoy Network (retrieved from http:/data.marine.ie).

To this end, we also examine the wave climate of Ireland for 29 years in the past: 1981 – 2009. The climate norms and averages for the Irish wave climate are determined using a 29 years wave model hindcast with wind forcing from the ERA-Interim re-analysis dataset[2] provided by European Centre for Medium-Range Weather Forecasts (ECMWF). This hindcast run can be seen as a best guess of the past climate and focuses in on Ireland at high resolution. It is also used to check that the EC-Earth driven wave climate model captures the climate norms and averages correctly. Thus we also perform a 29 years historical climate run (or control run) for the same period, forced with historical Met Éireann EC-Earth winds. This historical run can be imagined as a 'parallel Universe' where day to day values do not match observations, however, long term trends and averages should follow the real climate.

2. The wave model setup

We employ the Wavewatch III wave model[8] used for operational forecast by the National Oceanic and Atmospheric Administration (NOAA). The wave model consists in 3 nested grids (shown in Figure 2):

- Grid 1: North Atlantic: 1° x 1° latitude/longitude;
- Grid 2: Eastern North Atlantic: 0.333° x 0.333° latitude/longitude;
- Grid 3: Ireland: 0.1° x 0.1° latitude/longitude (about 10km).

The wave directional spectra are discretized into 32 frequencies (logarithmically spaced starting from 0.0373 Hz) and 24 equally spaced geographical directions. The 1-Minute Gridded Global Relief Data (ETOPO1) data set was used for the bathymetry of the model.

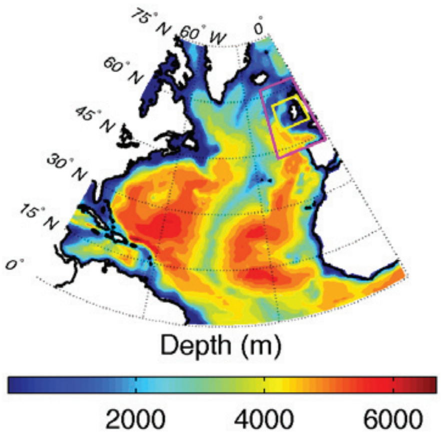

Fig. 2. Model domains for the 3 grids nested Wavewatch III wave model. Grid 1: North Atlantic basin, Grid 2: outlined in magenta. Grid 3: outlined in yellow.

3. Past wave climate for Ireland: 1981-2009

A 29-year hindcast (1981 – 2009) was performed as a representation of the actual past wave climate of Ireland. The quality of the hindcast was verified by comparison to measurements at the M3, M4 and M6 wave buoys from the Irish Marine Weather Buoy Network run by Met Éireann and the Marine Institute (See Figure 1 for the locations of the buoys). As can be seen in Table 1, the 29-year hindcast compares very well with the wave buoy measurements at the three locations off the west coast.

Given the relative 'youth' of the Irish Marine Weather Buoy Network (first deployments took place in 2001), the available measurements are still not sufficient to capture long-term changes in the climate. Therefore, the hindcast (which was validated with existing data) is a valuable tool to investigate this climate variability around Ireland.

Table 1. Comparison of the hindcast with measurements at the M3, M4 and M6 for the significant wave height.

	M3 buoy (2003-2010)	M4 buoy (2006-2010)	M6 buoy (2006-2010)
Mean (m)	2.9	3.1	3.47
Bias (m)	0.07	-0.04	0.02
RMSE (m)	0.56	0.49	0.51
Scatter index	0.19	0.16	0.14
Correlation coefficient	0.94	0.96	0.96

The annual and seasonal means of the significant wave height (Hs) for the hindcast are shown in Figure 3 (left panels). As can be seen in the figure, the annual mean significant wave height varies significantly from season to season, with a maximum of over 5m off the west coast in winter and under 1m on the east coast in summer. The similarity between the annual and the autumn mean significant wave height is striking. The right panels display the interannual variability in the means as the normalized standard deviation (%). This is a measure of how much the annual means vary from one year to the other. The annual mean significant wave height does not vary much around the coast. However, when looking at the individual seasons a more interesting picture emerges. In winter and spring the mean of significant wave height varies to a greater extent than in summer and autumn on the Atlantic west coast. On the east coast, the Irish Sea has increased variability compared to the Atlantic, however, this is relative to benign mean significant wave height values of about 1m.

The wave climate averages for the 29-year hindcast (the best guess of the past reality) and the 29-year historical climate run (a 'parallel Universe' run forced with EC-Earth global wind data) were compared. This was carried out in order to evaluate whether the wave model forced with the EC-Earth wind data can recreate the past wave climate of Ireland to a high quality. The difference between the 29-year hindcast and the 29-year historical mean significant wave height, at the level of the third high-resolution (0.1° x 0.1°) grid focused on Ireland are under 5% (even less than 2% for the Irish Sea), so we can have confidence that the historical wave climate run effectively simulates the wave climate averages for Ireland from 1981-2009. With this confidence in our model, we have performed a projection of the Irish wave climate into the future (from 2031-2060) using EC-Earth wind forcing, corresponding to the RCP 4.5 climate scenario.

4. Changes in the future wave climate: 2031-2060

To ascertain the changes in the wave climate, the 30-year wave climate projection into the future (2031-2060) was compared with the 29-year historical run (1981 – 2009), for both mean and highest sea-states. Consistent with recent global wave climate projection studies[3] our study reveals annual decreases in both mean significant wave heights and storm wave heights for the North Atlantic in general (Figure 4) and Ireland in particular (Figure 5). As can be seen in the Figure 4, there is a small decrease in annual mean significant wave height in the proximity of Ireland with the largest decrease occurring in winter. Large areas of increase in winter off the northeast coast of North America and south of Greenland are likely related to the retreat of Artic ice-cover in the future. Summer mean values exhibit a small decrease around Ireland, however there are areas of increased significant wave height to the south, off the coast of Spain and to the north, around the Icelandic coast.

Figure 5 presents the differences between future and past on the finest resolution grid focused on Ireland. The largest decrease in the mean values (over 20cm) can be seen off the southwest coast in winter. The mean significant wave height in winter is about 5m, so a decrease of 20cm should be considered relative to this mean significant wave height value. When we look at storm wave heights (highest 5% of significant wave heights), even though annual values show a small decrease around Ireland in the future, if we break this down by season considerable increases become evident. Spring becomes stormier in the north and northwest, with increases of over 20cm. Note that at the same time, large decreases can be seen off the southwest coast (same order of magnitude). A small increase in the north can also be seen in the winter.

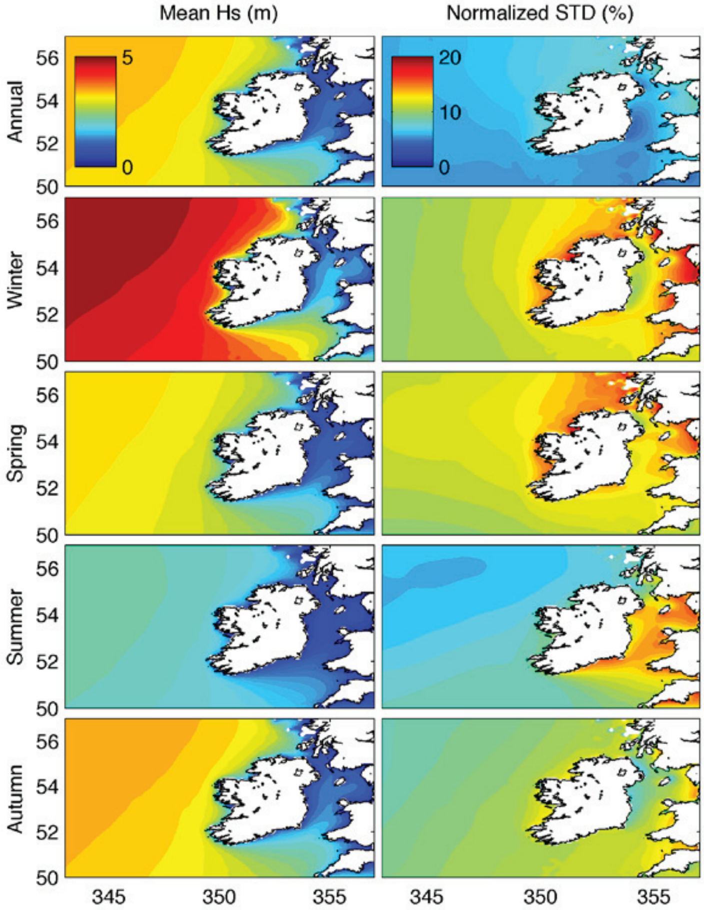

Fig. 3. The actual (past) wave climate of Ireland: 1981 – 2009. Left panels: the annual and seasonal mean significant wave heights. Right panels: normalized standard deviation of the means (%), which quantify the interannual variability.

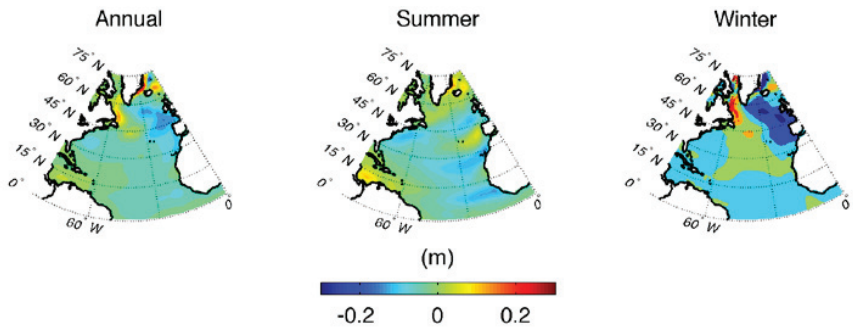

Fig. 4. Difference in the mean significant wave height values between the future (2031-2060) and the past (1981-2009) for the annual (top panel), summer (middle panel) and winter (bottom panel) values.

A look at the average of the annual maxima of significant wave height offers an interesting counterpoint to the overall decreases in the means - see Figure 6 where these values are displayed for the historical (past) and future runs respectively. Remarkably, this average is higher for the future than the past, in contrast with the mean of the highest 5% of sea-states (for which an overall annual decrease was observed, as Figure 6 reveals).

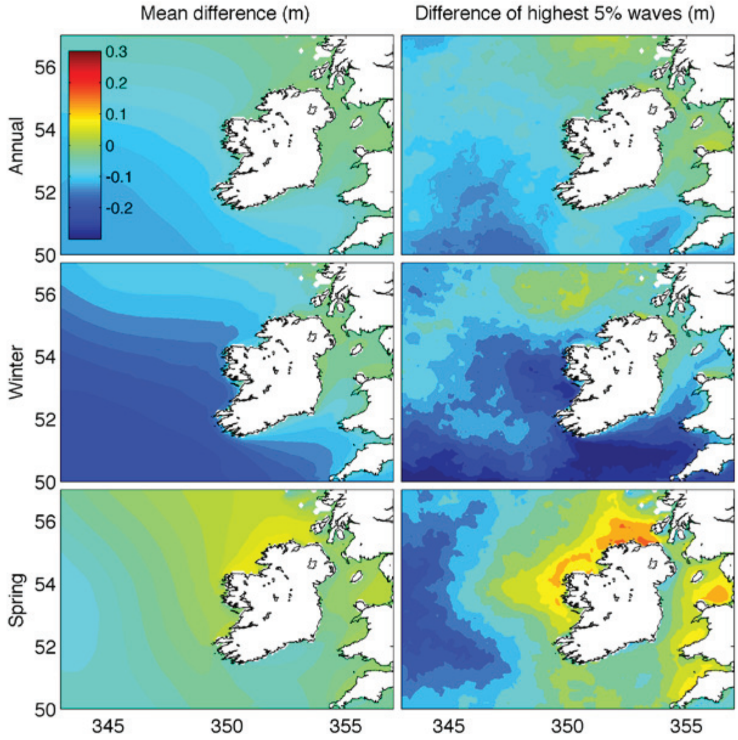

Figure 5: Annual and seasonal changes between the future (2031-2060) and the past (1981-2009) simulations: mean (left panels) and highest-5% (right panels) of significant wave heights (meters).

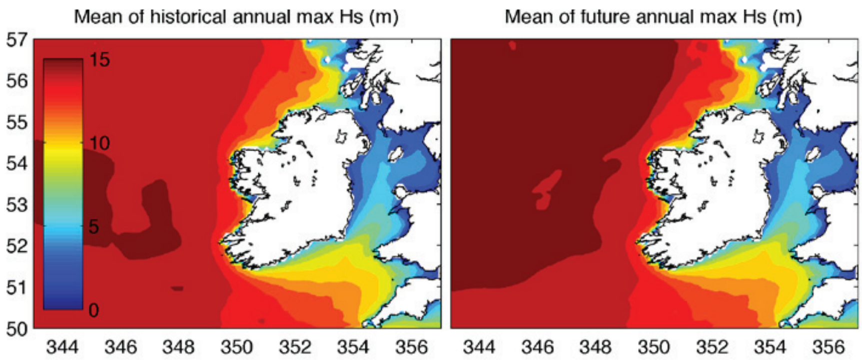

Figure 6: Historical (1981 - 2009) versus future (2031 - 2060) mean of the annual maxima of significant wave height (Hs).

It should be stressed however that annual maxima, being associated with individual storm events, are not as accurate a characterization of extreme sea-state occurrence. In other words, one large storm event can skew these values. In fact, a different realisation of the same forcing scenario may yield substantially different values of the maxima. The highest 5% of sea-states is a much more representative characterisation of the overall ‘storminess’ of the ocean.

5. Conclusions

In this study we have examined one realisation of one of the CMIP5 future carbon emission climate scenarios, RCP 4.5. An overall decrease in mean significant wave heights was found around Ireland (for the period 2031-2060 with respect to 1981-2009), with a maximum decrease in the winter mean reaching over 20cm. An increased storminess in winter and spring was found in the north and northwest.

The decrease in mean wave heights projected for the future could hint to a slight reduction in the wave energy resource. However, this is expected to have a minimal impact on the huge overall potential for wave energy exploitation in Ireland, particularly on the west coast. At the same time, our study reveals a significant interannual variability in the Irish wave climate, which should be taken into account when estimating the wave energy resource.

We stress that our findings should be interpreted with caution, for the following reasons: (i) to account for uncertainty and variability of the climate model, an ensemble of realisations should be investigated; (ii) furthermore, other forcing scenarios should be explored in order to address the uncertainty in future carbon emissions of the planet; (iii) finally, to resolve the variability of the wave climate in the nearshore, a higher resolution downscaling would be required around Ireland. This work is currently underway in the UCD Wave Group.

Acknowledgements

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