Changes in the wave climate during the 21st century - results from the CLIMENA project

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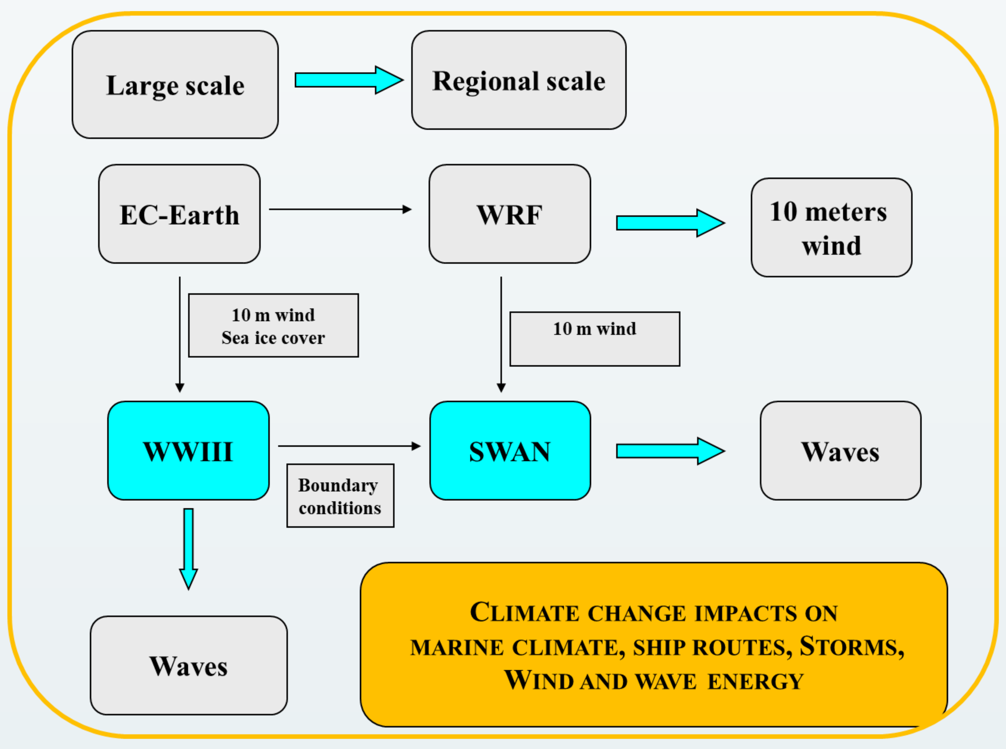
Abstract

An improved understanding of the present and future marine climatology is necessary for numerous activities, such as the operation of offshore structures, optimization of ship routes, and evaluation of wave energy resources.
The WAVEWATCH III wave model was used to produce wave information, until the end of the 21st century, covering all ocean areas. Global wind and ice-cover climate data from a total of 120 years were used as input for the wave model. The period is divided into four 30-year slices, where the first (1980–2009) represents the recent past, the second (2010–2039) the near future, the third (2040–2069) the mid-century and the last one (2070–2099) represents the end of the 21st century.
Descriptive empirical statistics of wind and wave parameters were obtained for different 30-year time slices, for the North Atlantic Ocean. Changes from present to future climate were evaluated, regarding both mean and extreme events. The results showed a decrease of mean significant wave height of total sea in the North Atlantic. Other regions also present changes but are less marked and less consistent through time.
The simulated wave data was also used for different application as the evaluation of future wave storm conditions in the North Atlantic Ocean using a Lagrangian methodology, the analyses of the relationship between the Arctic Oscillation index and present and future met ocean conditions on the North Atlantic Ocean.

Objectives and methodology

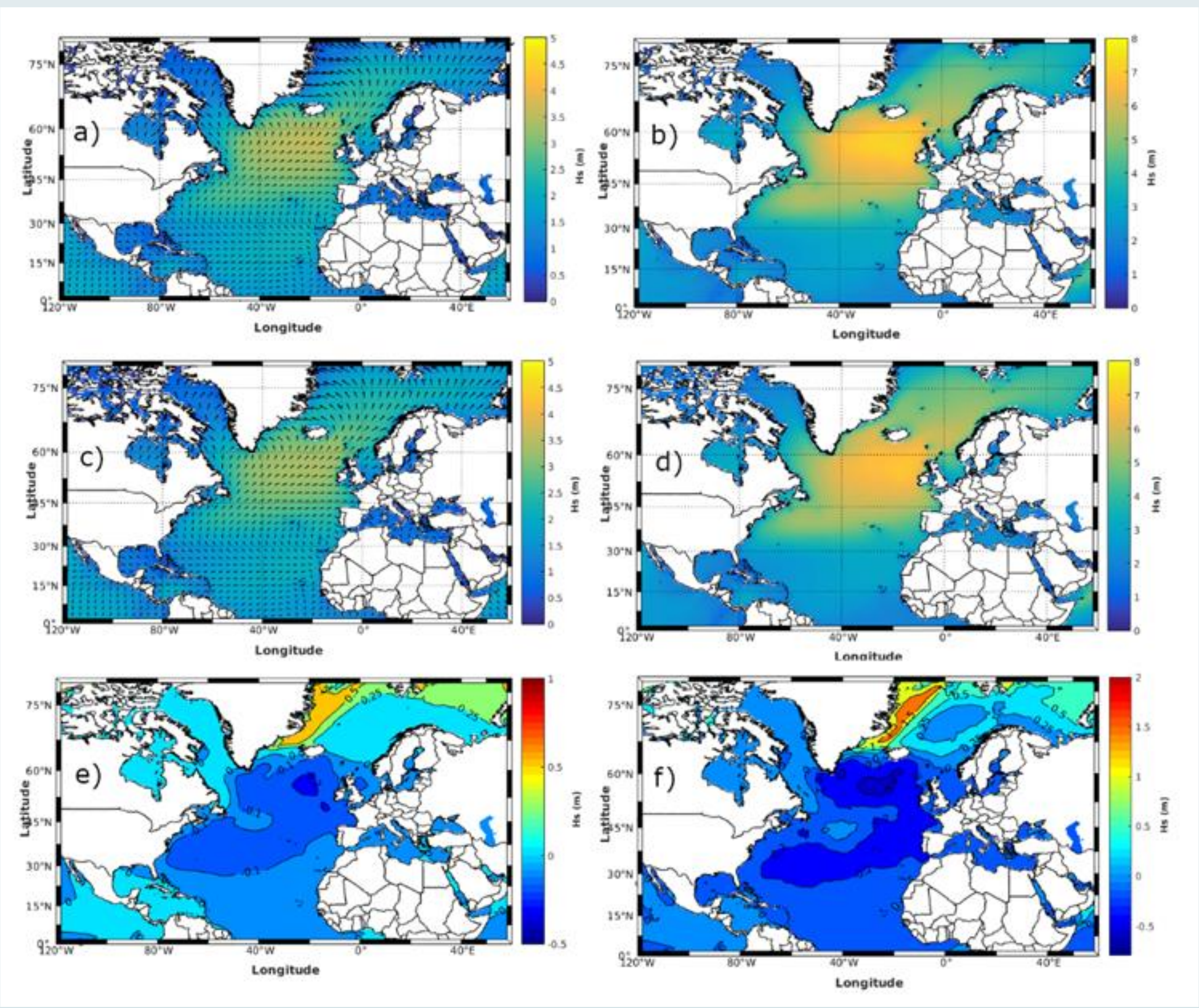


The main objective of this project was to study the impacts of climate change in the North Atlantic wind and wave climate and then focus on the coast of the Iberian Peninsula and Portuguese Atlantic Islands. The project started by simulating the waves in the North Atlantic using the WAVEWATCH III model, and wind and sea-ice cover information an EC-Earth simulation (CMIP5 forced by RCP8.5 emission scenario and then, produce different regional climate simulations using the SWAN model. In a second stage, simulated data was used to evaluate changes at different spatial and temporal scales, relate it to large scale atmospheric regimes, study storm characteristics under climate change conditions and assess changes in wave and wind resources.

Some results obtained regarding large scale analysis are presented.

North Atlantic wave climate

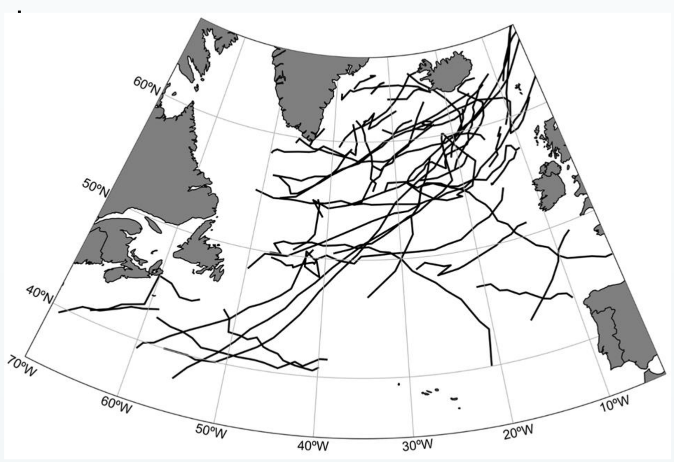
To produce the wave climate information, the WAVEWATCH III model was forced with wind and sea-ice cover information from one CMIP5 model, the EC-Earth, using the RCP8.5 emission scenario. The 120 years simulation was divided into four periods of 30 years. The first one (1980-2009) represents the recent past, the second (2010-2039) the present climate, the third (2040-2069) the mid-century and finally the last (2070-2099) represents the end of the 21st century.
Changes from present to future climate were assessed, comparing the empirical statistics between time slices.



Mean (left panel) significant wave height (and mean direction) and 95th percentile (right panel) for recent past (top), end of 21st century (middle) and difference between them (bottom).

Storm characteristics under climate change conditions

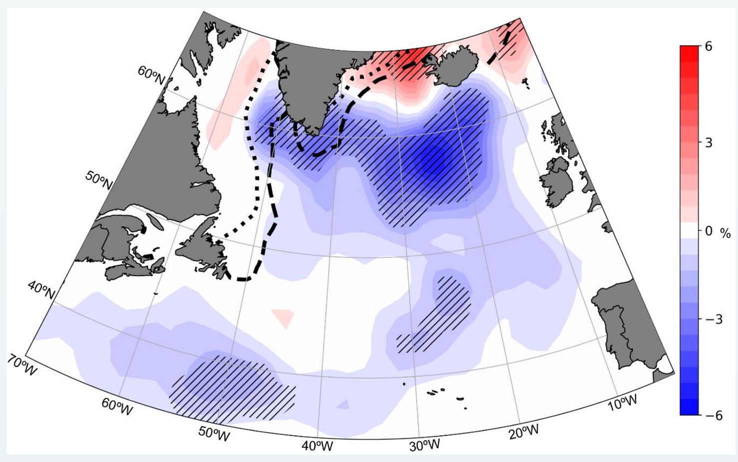
Wave storms are generated by severe weather conditions and can be considered as a spatial-temporal phenomenon where the significant wave height rises above a critical threshold and stands above it for a time interval greater than 12 hours.
These storm sea states affect a variety of human activities and represents a risk for ship safety as severe conditions imply longer journeys and higher fuel consumption. In the North Atlantic Ocean, which presents one of the world's most intensely trafficked ship routes and presents varied economic activity, such as natural resources exploitation (e.g., fishing, crude oil, natural gas), this especially important. The operation and safety of these economic activities depend upon favorable weather conditions as calm sea states.
The projected future wave storm conditions in the North Atlantic Ocean were investigated using a Lagrangian methodology applied to a 120 years (1980-2100) dataset resulting from a run of the WW3 model forced by EC-Earth winds and ice cover under the RCP8.5 climate change scenario. Several wave storm temporal-spatial characteristics were analysed, among them the number of storms, storm maximum significant wave height (HSmax), maximum storm area, storm area associated with HSmax, storm track distribution and duration...



Wave storms tracks identified in 1997 winter.

Annual mean, minimum and maximum, confidence interval, standard deviation of wave storm characteristics and Kruskal-Wallis p-value from differences for each parameter between the end of the 21st century (2070-2100) and recent past (1980-2010). The values with statistically significant changes at the 5% level are in bold.

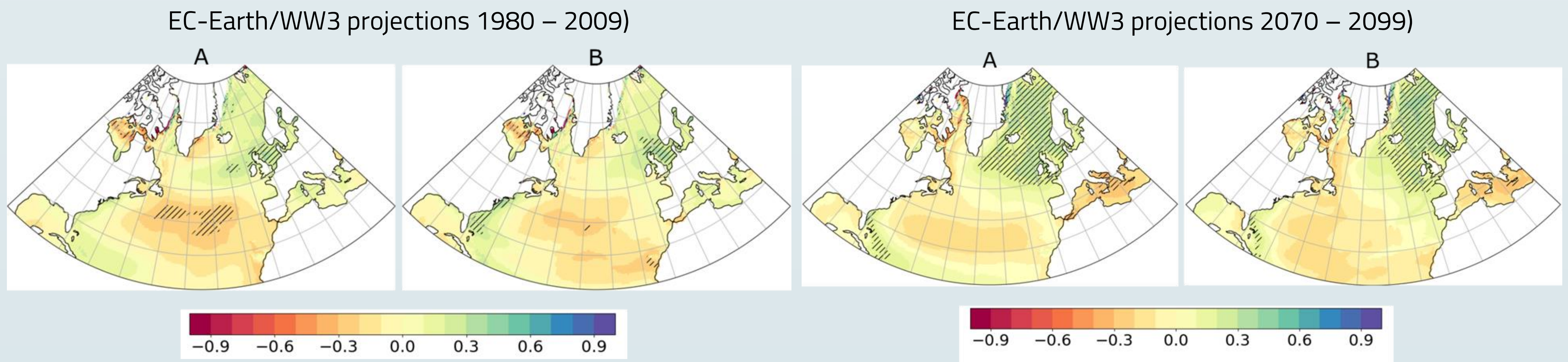
	years interval	mean	min – max	CI	STD	KW p-value
Number of wave storms	1980 - 2010	105.6	79 - 126	101.6 - 109.6	10.5	**0.00002**
	2070 - 2100	91.9	74 – 117	87.7 - 95.9	10.8	
Wave storm duration (h)	1980 - 2010	35.2	12 - 147	34.5 - 35.9	1.9	0.42037
	2070 - 2100	35.7	12 – 141	34.9 - 36.4	2.1	
Wave storm HSmax (m)	1980 - 2010	9.41	7 - 19.2	9.34 - 9.48	0.19	**0.01949**
	2070 - 2100	9.56	7 - 19.8	9.46 - 9.65	0.25	
Wave storm area of HSmax (km^2)	1980 - 2010	498.7	11.4 - 4355.2	476.7 - 521.0	58.3	0.79014
	2070 - 2100	492.2	11.4 - 4355.2	462.1 - 522.1	79.2	
Maximum area of wave storms (km^2)	1980 - 2010	591.7	11.4 - 5094.7	565.6 - 617.8	68.6	0.95284
	2070 - 2100	592.0	12.2 - 5506.5	556.1 - 627.6	94.4	
Wave storm tracks distance (km)	1980 - 2010	1316.7	0 - 6455	1284.6 - 1348.8	84.6	0.19835
	2070 - 2100	1353.8	0 - 6332	1312.5 - 1395.0	108.6	



Percentage change of wave storms tracks distribution by the end of the 21st century (2070-2100) relative to the 1980-2010 period. The regions with statistically significant changes at the 5% level are hatched. The maximum ice cover is marked in black lines hatched for the 1980-2010 period and dotted for the 2070-2100 period.

Arctic oscillation

Storms, and consequently waves, show large decadal and interdecadal variability. Storms frequency has seasonal variability, being more frequent from October to March, in the North Atlantic, and an interannual frequency variability that affects ocean. One of the factors that affect storms variability is the large-scale atmospheric oscillation as the North Atlantic Oscillation (NAO) and the Arctic Oscillation (AO), that represent climatic relationships between non-contiguous geographic regions.
The AO can be characterized as an exchange of atmospheric mass between the Arctic Ocean and the surrounding zonal ring centred ~45°N. It may also be related with the characteristics of the wave regimes in the North Atlantic such as period and energy, as these are associated not only with wind but also with the fetch.
Changes in the Arctic Oscillation (AO) index by the end of the 21st century and its relationship with present and future metocean conditions on North Atlantic Ocean were analysed in project CLIMENA.



Spatial correlation between Arctic Oscillation Index and (A) ocean wave height and (B) wave peak for winter months for the present (EC-Earth/WW3 simulations 1980 – 2009) climate. Hatched areas represent points that are statistically significant at the 80% confidence level.

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