Historical wave energy trends in the Bay of Biscay (1900-2010)

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Introduction

This study analyses the influence of wave energy trends on the evolution of wave energy flux and on the absorbed power of wave energy converters during the last century. For the moment, the study has being developed in Western Europe (mainly Portugal, France, Bay of Biscay and Ireland), because our first general studies in Europe show that the trends are relevant in the open Atlantic Ocean. The Mediterranean, Baltic Sea or North Sea do not exhibit significant changes.

Different studies about wave trends presented in the literature to date and to the best knowledge of the authors, have been focused mainly on the variation of the wave height. These studies on wave trends typically use data from four different sources: in situ measurements by buoys, wave observations from ships, satellite altimeter, and model and reanalysis datasets. In our previous work, we cite the most important data sources (Ulazia et al. 2017). For comparison purposes, the most relevant study carried out so far, Young et al. (2011) uses satellite altimeter data and presents a spatially distributed account of wave height trends around the world. All our results are coherent with Young's trend maps.

Data and methodology

ERA20C reanalysis of the last century from the European Centre for Medium-Range Weather Forecasts (ECMWF, Poli et al. 2016) has been calibrated via quantile-matching against the ERA-Interim-WAM reanalysis (Dee et al. 2011) during their common period (1979-2010). The validation against buoys in the Bay of Biscay has been carried out by means of Taylor Diagrams using three statistical indicators: correlation, RMSE (root mean square error) and SD ratio (the ratio between the standard deviation of the reanalyses and the standard deviation of the buoys' observations).

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After the construction of the transference function for the mentioned intersection period, the calibration has been extended to all time series covered by ERA20C, that is, 110 years starting at 1900. The Theil-Sen method provides robust estimations of trends present in time series. This method has been used to estimate decadal trends at a 95% confidence level of the wave energy flux at each grid point.

Results

The validation shows a better agreement of ERA-Interim-WAM model if compared to the original ERA20C. Moreover, calibrated ERA20C (cERA20) shows a significant error reduction compared to the original ERA20C, mainly in RMSE and in the SD ratio, not so much in correlation. Here, the Taylor Diagram for the Bilbao-Vizcaya buoy is shown for the pure ERA20 data, ERA-Interim and the calibrated cERA20 (see Figure 1).

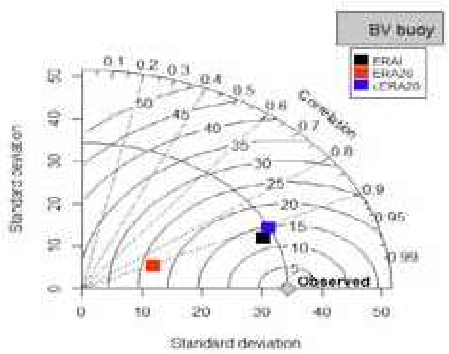

Figure 1. Taylor Diagram in the Bilbao-Vizcaya buoy.

The calibrated ERA20C presents an increase of the wave energy resource, more than 1 kW/m per decade, in the area of study delimited by the Bay of Biscay (see Figure 2), and a general increase of the wave height and wave period throughout the analysed decades.

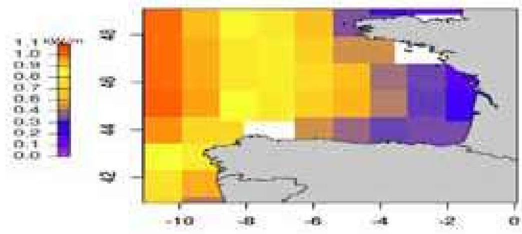

Figure 2. Wave Energy Flux decadal trend in the Bay of Biscay.

Apart from that, the wave trend map for Europe has also been represented to obtain a general overview, where the strong trends off West Ireland show a hot area and the neutral trends of Mediterranean Sea show lower values. Figure 3 shows these results using the data from the reanalysis ERA20C of the last century (see methodology) without calibration and represents the decadal increment of maximum individual wave height in centimetres and its period in centiseconds. In the West of Ireland, there are locations with positive significant trends above 1 meter and 0.5 seconds per century. Maximum values instead of mean values are chosen to emphasize the important increments involved. We are talking about relative incremental values of more than 10% in a century. This means an important increment in wave energy flux since it is proportional to the square of the wave height and the period. Furthermore, these maps offer a relative view of wave trends in the Bay of Biscay: although the wave period trends are similar to open Atlantic Ocean's trend, the diminution is clear inside the Bay of Biscay in wave height trend.

Finally, using the calibrated series at a given grid point in the Bay nearest the Bilbao-Vizcaya buoy, power absorption of a generic wave energy converter (WEC) is also examined during the five do-decades of the past century. The generation increments with respect to 1900-20 do-decade are similar to wave energy flux increment (WEF), that is, the square of the significant wave height (Hs) times the increment of mean wave period (Tm) (see Table 1).

Conclusions

Results show important variations of the wave energy flux and consequently the WEC's PDF, which results in significant differences, up to a 15% increase between the last two do-decades, and a significant gap in the 1940-60 years. Any strategy to develop wave energy in the Bay of Biscay must incorporate this upward trend for its implications not only regarding an increase in energy availability but also for its impact on coastal infrastructures. Future research will be carried out regarding the likely evolution of these fields under climatic change scenarios. Since WAM data will not be available for most of the CMIP5 or CMIP6 models, an intermediate estimation by means of statistical downscaling models is necessary for these climate change scenario-based assessments.

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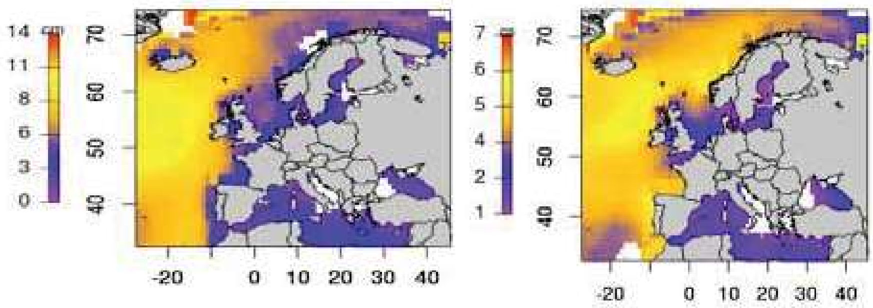

Figure 3. Decadal trends of maximum wave height and maximum wave period in Europe according to ERA20C.

Table 1. Hs and Tm and WEF mean values in each do-decade and the increments in percent with respect to the first do-decade.

	1900-20	1920-40	1940-60	1960-80	1980-2000
Hs (meters/ increment in %)	1.57 / -	1.58 / 0%	1.64 / 4%	1.74 / 11%	1.80 / 15%
Tm (seconds / increment in %)	8.20 / -	8.28/ 1%	8.54 / 4%	8.64 / 5%	8.75 / 7%
WEF (kW/m / increment in %)	10.48 / -	10.60 / 0 %	11.21 / 7%	12.83 / 22%	13.75 / 32%