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"L'ingegneria delle acque in un mondo in rapida evoluzione: nuove sfide e soluzioni per un futuro sostenibile e per una società più resiliente"

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CLIMATE CHANGE IMPACT ON EXTREME WAVE CONDITIONS OFF ITALIAN COASTS

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KEY POINTS

- *Extreme wave events affected by climate change scenarios, analysis on reconstructed past/present time series and forecast time series of future projections*
- *Statistical analysis aimed at defining the correlation between return periods and return levels*
- *Climate change scenarios defined by IPCC report (RCP4.5 and RCP8.5)*

1 INTRODUCTION

In the last decades, extreme events have caught general attention as being often associated with threatening natural phenomena that, due to global warming increase, occur with growing frequency and intensity (*Seneviratne et al., 2021*). Such phenomena can significantly impact both natural and anthropic environments, causing damage to ecosystems and local biodiversity, as well as to infrastructures and socioeconomic ambient. Floods, storm waves, storm surge events, and others; their effects require implementing mitigation systems and long-term adaptation strategies (*Pasquali et al., 2023*). For this reason, it is particularly important to monitor changes over time in the physical parameters that characterize specific natural phenomena. In coastal areas, climate change may affect wind patterns, sea levels, and the characteristics of sea states in terms of both frequency and intensity. The inclusion of these possible variations is particularly relevant not only for coastal flooding risk analysis (*Baldoni et al., 2024*) but also for the detection of the design wave into civil engineering practice (*Goda, 1980*).

2 METHODOLOGY

Statistical analysis of extreme events aims to identify the synthetic characteristics of storm waves that are expected to show quantitative changes in future climate change scenarios. In time series analysis, extreme events represent exceptions that differ from the normal pattern of other values. The essence of an extreme value analysis lies, then, in the goal of measuring the stochastic behavior of a process at extremely high or low levels, distinguished by its focus on levels out of the ordinary (*Coles et al., 2001*). To perform an accurate statistical analysis of extreme data, it is first necessary to verify that the starting observed time series is statistically representative. Subsequently, extraction of extreme values can be carried out by using two main methods that find their basis in extreme value theory (EVT): block maxima method and threshold model (*Coles et al., 2001*). The choice of extraction method is influenced by the verification of the condition of statistical independence and homogeneity of the data sample extracted from the sample population, which must always be guaranteed. The extracted values are then submitted to a process of statistical inference, aiming to elaborate the best fit between the observed data and known theoretical probabilistic functions. In this domain, the goal is to associate return levels, representing synthetic wave parameters, with assigned return periods or relative probabilities of exceedance. In scientific domains, especially in the hydrological field, return period refers to the average time interval between occurrences of events with a certain magnitude or intensity, so the average time between occurrences of events surpassing a certain threshold. It therefore relates to the frequency with which events above a certain threshold will occur (*Volpi, 2019*).

3 DATASET

In this case study, analyses are applied to a large dataset composed by measured data from direct measurements of ondametric buoys provided by ISPRA (National Ondametric Network) and local administrative authorities (e.g. Regions and Port System Authorities), reconstructed time series derived from the ERA5-Reanalysis database, with time coverage from 1940 to the present (*Hersbach et al., 2020*) and forecast future time series based on climate change scenarios (2041 to 2100), provided by the Copernicus Climate Service (C3S), in collaboration with the European Centre for Medium-Range Weather Forecasting (ECMWF, *Buontempo et al., 2022*). The latter dataset provides an overview of the wave climate under the impact of climate change for the northwestern European shelf and the Mediterranean Sea. The datasets are projected on future climate change scenarios based on "Representative Concentration Pathways," covering a period from 2041 to 2100. These scenarios differ in the level of atmospheric concentration of greenhouse emissions expected in the future and are used to assess the potential effects of climate change on the environment. The number associated with each RCP (2.6, 6.0, 4.5, 8.5) is related to the Radiative Forcing (RF), which is a measure of the influence of a factor to affect the energy input and output balance in the climate system (*Meinshausen et al., 2011*). In this paper, our focus will be on the RCP4.5 scenario, which represents a future with moderate greenhouse gas emissions, with an increase until mid-century, followed by a gradual decrease, and the RCP8.5 scenario, which represents a future with very high greenhouse gas emissions, with a continuous increase (i.e., a future in the absence of significant climate change mitigation policies). The use of this integrative approach allows the inclusion of wave climate response concerning climate change. The results that will be presented in this paper are part of a large-scale PNRR "RETURN" project that will be implemented on several stretches of the Italian coast.

4 APPLICATION AND RESULTS

4.1 Case of study

Preliminary analyses were carried out on two points of interest located off the Calabrian Tyrrhenian coast, near Cetraro, and off the Adriatic coast of Abruzzo, near Ortona, respectively. The geographical coordinates of the ondametric wave buoys of Cetraro and Ortona (National Ondametric Network - ISPRA) were considered as reference points. The time series of ERA5 and future RCPs scenarios were extrapolated to the coordinate point closest to the buoy coordinates, considering the spatial resolution of the reconstructed data. The time series of measured data from the Cetraro and Ortona buoys (see Figure 1) will be used for a second time to validate data from the ERA5 database.

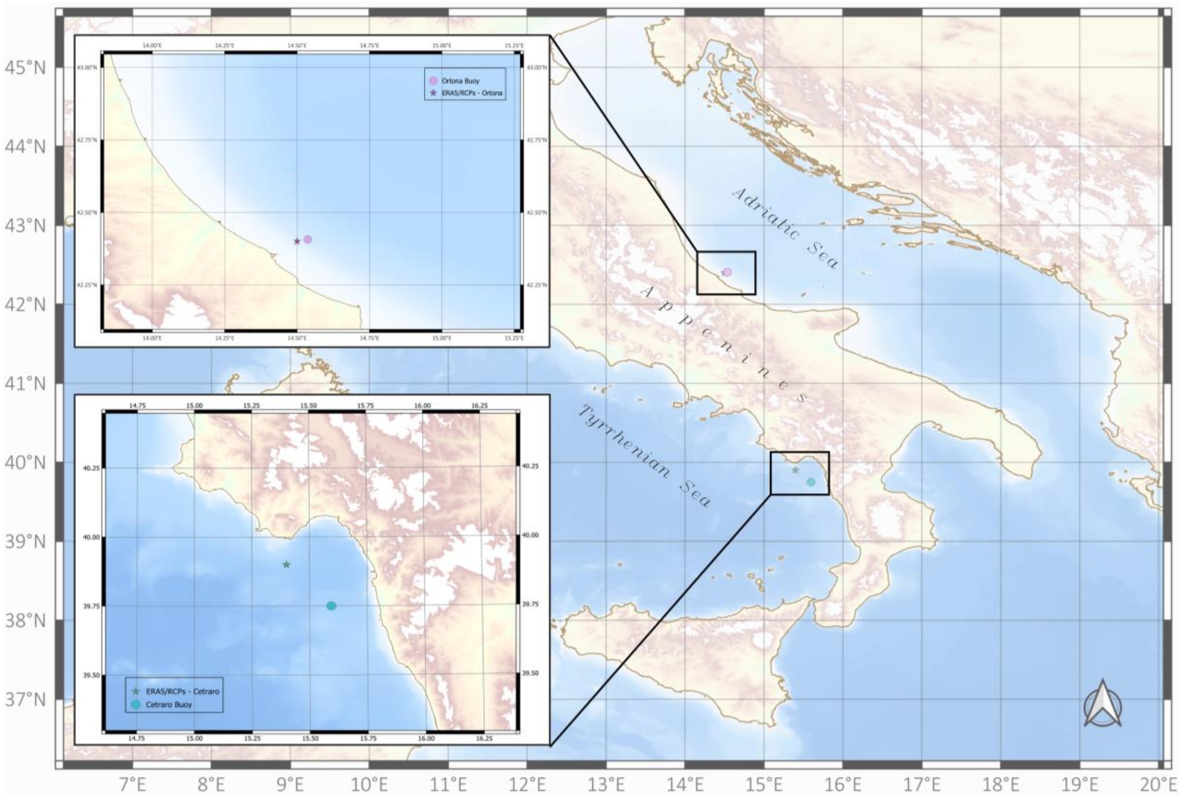

Figura 1. Geographical setting of the study area.

The geographical and temporal information on the used datasets are also reported in Table 1.

	ID	Depth (m)	Position Lat (°N) – Lon (°E)		Temporal Coverage (years)
RCPs	**Cetraro**	20	39.90	15.40	2041-2100
	Ortona	20	42.40	14.50	2041-2100
ERA5 Reanalysis	**Cetraro**	20	39.75	15.50	1940-today
	Ortona	20	42.50	14.50	1940-today
Wave Buoys	**Cetraro**	100	39.75	15.38	1989-2014
	Ortona	50	42.40	14.54	1989-2011

Table 1. Geographical and temporal characterization of the RCPs, ERA5 Reanalysis, and the ondametric buoys.

4.2 Extreme Value Analysis

An omnidirectional statistical analysis of extreme wave conditions was developed to evaluate the possible variations in return levels at the assigned return periods between the past/current scenarios represented by the ERA5 database and the future scenarios represented by RCP4.5 and 8.5. In this context, the significant wave height Hs will be considered as a representative synthetic parameter of sea states. Values of return periods commonly used in engineering to understand the response of structures to certain hydraulic phenomena, but also in risk analysis, were chosen. Extreme sampling values were extracted by the Peak Over Threshold method, applying a declustering period of 48h to ensure independence among the extracted values. The threshold value picked for the different time scenarios (current and future) was selected using the “mean residual life plot” method (*Coles et al., 2001*), observing the trend of the mean of the extreme values as the possible threshold values variation. In addition, Goda's censoring parameter ν was taken into account (*Goda, 1980*). Applying the method of extremes over the threshold, the extreme events of the extracted sample can be said to be theoretically represented by a continuous random variable with a probability distribution function equal to the Generalized Pareto Distribution (GPD). The statistical inference has been performed by means of the maximum likelihood estimation (MLE) method. As a preliminary result, the comparison of patterns of significant extremal wave height values as a function of return period for the current ERA5-Reanalysis scenario (non-calibrated) and the two future scenarios RCP4.5 and RCP8.5 for Cetraro (Calabria Regium) and Ortona (Abruzzo Regium) is shown. The results related to Cetraro are displayed in Figure 2.

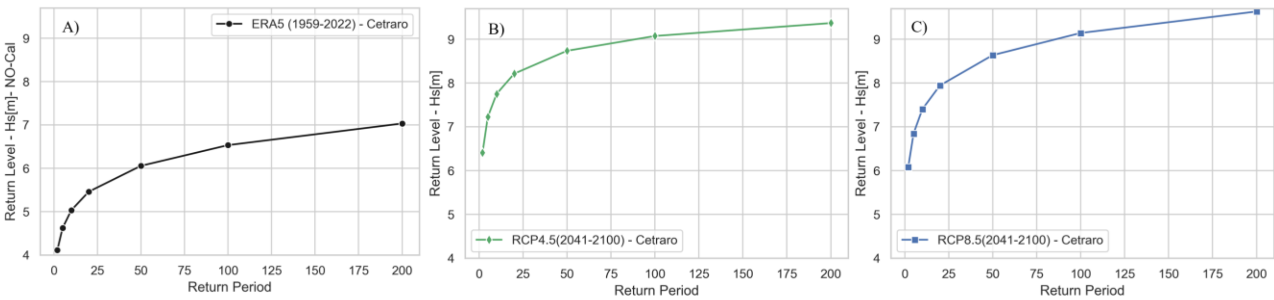

Figura 2. Comparison of extracted return levels (Hs [m]) as a function of return period (years) in the current uncalibrated scenario (panel A), RCP4.5 scenario (panel B), and RCP8.5 scenario (panel C) – Cetraro (Calabria).

In panel A of Figure 2, the return levels are derived from the ERA5-Reanalysis dataset, while in panels B and C, they correspond to RCP4.5 and RCP8.5, respectively. A significant difference between the ERA5-Reanalysis data and the RCPs is evident. Upon comparing the return level values across the RCPs, it is possible to observe that RCP4.5 yields higher values for lower return periods than RCP8.5. Conversely, for higher return periods, RCP8.5 demonstrates slightly higher return level values when compared to RCP4.5.

In Figure 3, the results related to Ortona are shown.

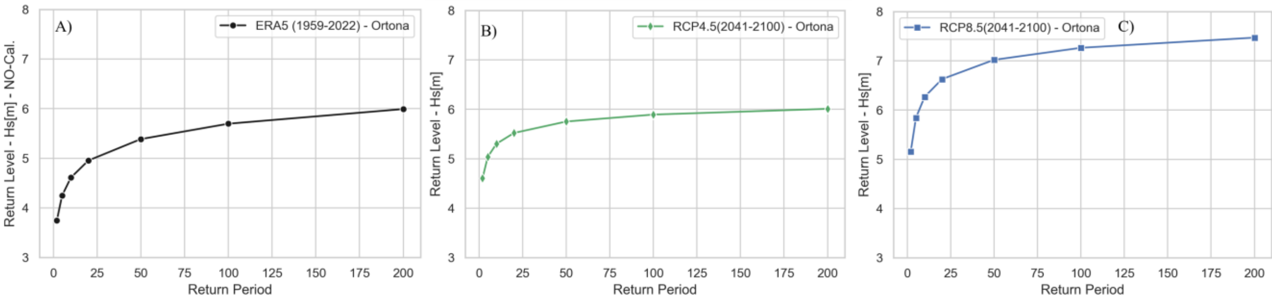

Figura 3. Comparison of extracted return levels (Hs [m]) as a function of return periods (years) in the current uncalibrated scenario (panel A), RCP4.5 scenario (panel B), and RCP8.5 scenario (panel C) – Ortona (Abruzzo).

Unlike the observations made for the Cetraro results, the return levels obtained from the ERA5-Reanalysis and RCP4.5 datasets are quite comparable (as was expected) particularly when examining high return periods. The main difference arises when comparing future scenarios (RCP4.5 and RCP8.5). The more severe scenario leads to an increase in the return level values, especially for high return periods. This finding is consistent with the IPCC description, wherein the RCP8.5 scenario is characterized as the worst-case scenario compared to RCP4.5.

The results presented in this paper should be considered preliminary, and some of the ongoing developments will be showcased during the conference.

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