

Supplementary Material

1 SUPPLEMENTARY TABLES AND FIGURES

In the following, more details about the characterization of the extreme wave climate for the site of Catania are provided. Moreover, the results of the analysis of the convergence of outputs of the Monte Carlo (MC) simulations performed for the assessment of the structure failure probability during lifetime ($P_{f,L}$) are displayed.

1.1 Characterization of extreme wave climate for the site of Catania

Table S1. Parameters of the Weibull distribution of the extreme significant wave height (H_{s0}) calculated for the present and future scenarios (α_{sc} = scale parameter, κ_{sh} = shape parameter, ζ_{lc} = location parameter).

Scenario	Sub-period	α_{sc}	κ_{sh}	ζ_{lc}
Present	1989-2005	1.14	1.30	1.56
	2071-2087	1.53	1.73	1.29
	2072-2088	1.59	1.78	1.27
	2073-2089	1.61	1.80	1.26
	2074-2090	1.40	1.70	1.35
	2075-2091	1.38	1.71	1.35
	2076-2092	1.37	1.69	1.35
	2077-2093	1.44	1.70	1.32
	2078-2094	1.38	1.64	1.36
	2079-2095	1.42	1.69	1.34
	2080-2096	1.44	1.65	1.36
	2081-2097	1.38	1.60	1.38
	2082-2098	1.35	1.58	1.40
	2083-2099	1.29	1.53	1.43
	2084-2100	1.33	1.49	1.41
RCP4.5	2041-2057	1.29	1.84	1.43
	2042-2058	1.30	1.82	1.40
	2043-2059	1.24	1.76	1.41
	2044-2060	1.27	1.77	1.39
	2045-2061	1.22	1.73	1.41
	2046-2062	1.28	1.78	1.39
	2047-2063	1.32	1.80	1.36
	2048-2064	1.26	1.76	1.39
	2049-2065	1.26	1.78	1.39
	2050-2066	1.24	1.63	1.45
	2051-2067	1.27	1.64	1.43
	2052-2068	1.18	1.56	1.46
	2053-2069	1.13	1.34	1.52
	2054-2070	1.07	1.33	1.56
RCP8.5	2041-2057	1.29	1.84	1.43
	2042-2058	1.30	1.82	1.40
	2043-2059	1.24	1.76	1.41
	2044-2060	1.27	1.77	1.39
	2045-2061	1.22	1.73	1.41
	2046-2062	1.28	1.78	1.39
	2047-2063	1.32	1.80	1.36
	2048-2064	1.26	1.76	1.39
	2049-2065	1.26	1.78	1.39
	2050-2066	1.24	1.63	1.45
	2051-2067	1.27	1.64	1.43
	2052-2068	1.18	1.56	1.46
	2053-2069	1.13	1.34	1.52
	2054-2070	1.07	1.33	1.56

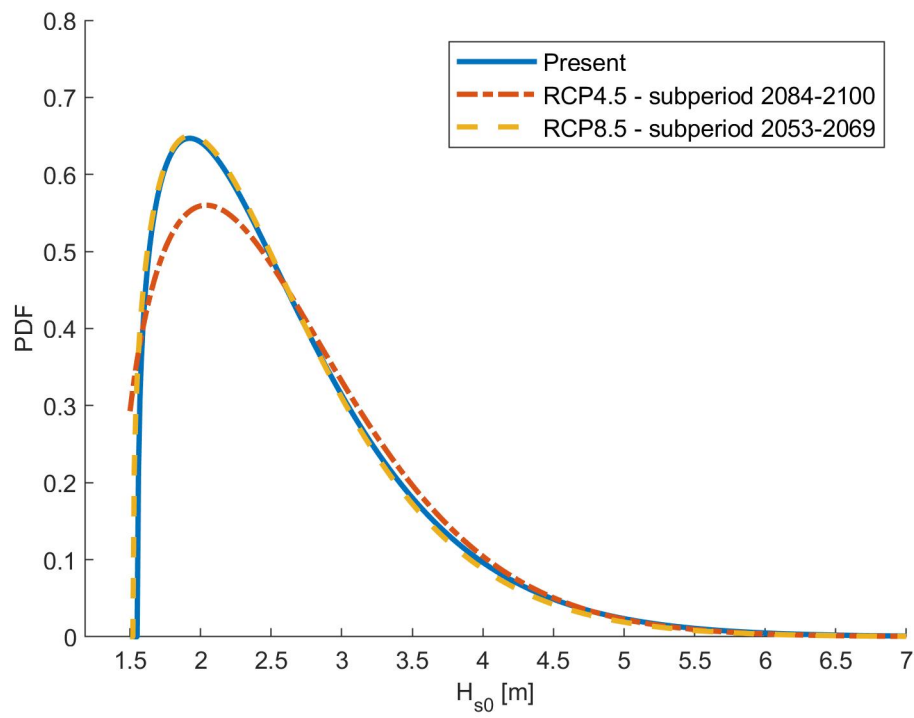


Figure S1. Comparison between the Weibull probability density functions (PDF) of extreme H_{s0} calculated for the present period and two future sub-periods under RCP4.5 and RCP8.5 scenarios.

Table S2. Estimate and 95% confidence bounds (*CB*) of the coefficient b_{T_m} of the site-specific empirical relationship between H_{s0} and T_{m0} defined for present, RCP4.5 and RCP8.5 scenarios.

Scenario	Sub-period	Estimate	Lower 95% <i>CB</i>	Upper 95% <i>CB</i>
Present	1989-2005	8.693	8.491	8.895
RCP4.5	2071-2087	7.956	7.800	8.113
	2072-2088	7.979	7.820	8.137
	2073-2089	7.930	7.778	8.083
	2074-2090	7.997	7.837	8.157
	2075-2091	7.982	7.830	8.133
	2076-2092	7.976	7.820	8.132
	2077-2093	7.967	7.805	8.130
	2078-2094	7.955	7.797	8.113
	2079-2095	7.937	7.779	8.096
	2080-2096	7.906	7.754	8.058
	2081-2097	7.902	7.754	8.050
	2082-2098	7.885	7.740	8.031
	2083-2099	7.845	7.710	7.981
	2084-2100	7.831	7.691	7.972
RCP8.5	2041-2057	7.958	7.813	8.103
	2042-2058	7.907	7.768	8.045
	2043-2059	7.922	7.780	8.064
	2044-2060	7.917	7.777	8.057
	2045-2061	7.911	7.769	8.052
	2046-2062	7.903	7.760	8.045
	2047-2063	7.919	7.775	8.063
	2048-2064	7.952	7.804	8.101
	2049-2065	7.946	7.799	8.093
	2050-2066	7.909	7.762	8.056
	2051-2067	7.887	7.738	8.036
	2052-2068	7.918	7.768	8.067
	2053-2069	7.915	7.765	8.065
	2054-2070	7.926	7.778	8.074

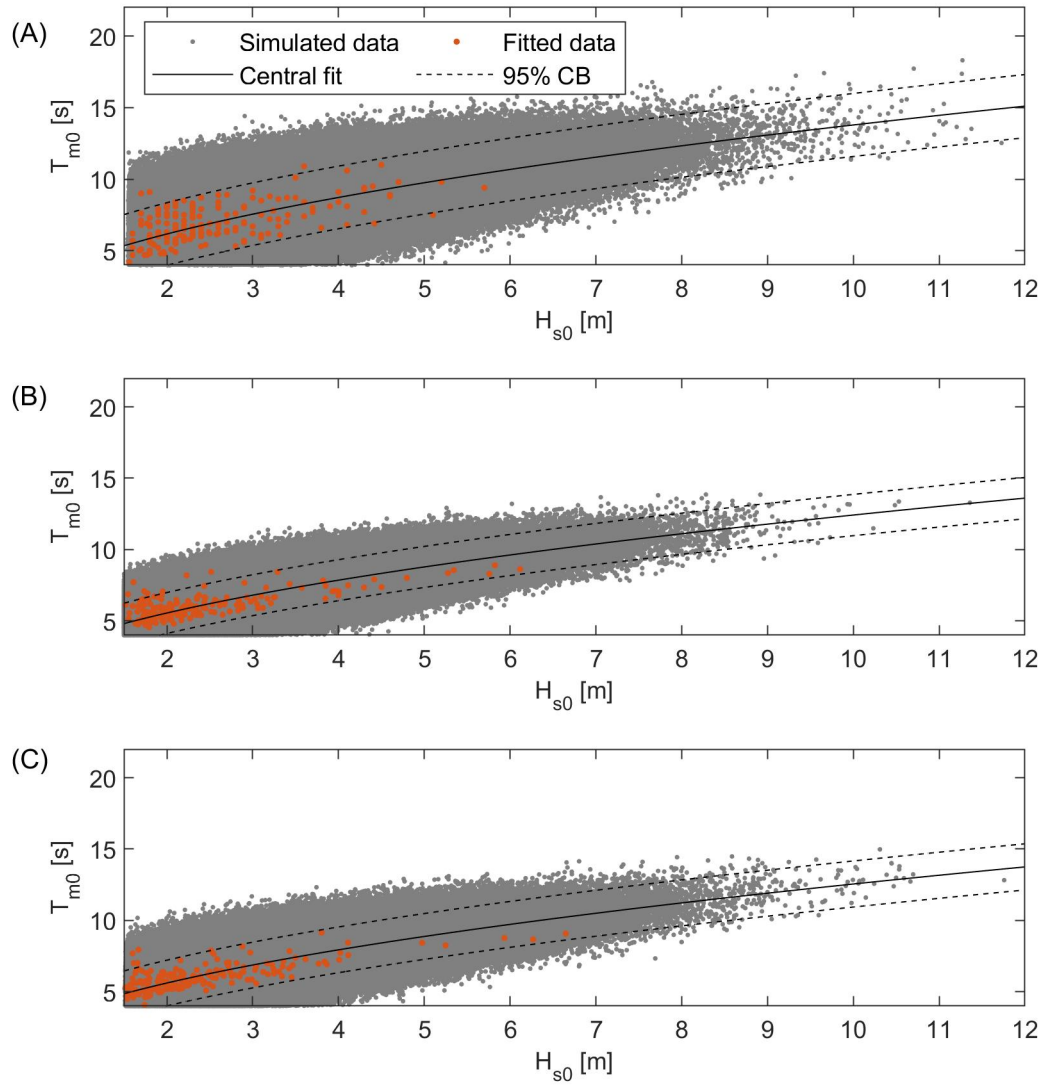


Figure S2. Central fit and 95% confidence bounds of the site-specific empirical relationship between H_{s0} and T_{m0} : (A) (1989-2005); (B) sub-period 2084-2100 under RCP4.5 scenario; (C) sub-period 2053-2069 under RCP8.5 scenario.

Table S3. Estimate and 95% confidence bounds (*CB*) of the coefficient b_{ds} (hours/m) of the site-specific empirical relationship between H_{s0} and d_s defined for present, RCP4.5 and RCP8.5 scenarios.

Scenario	Sub-period	Estimate	Lower 95% <i>CB</i>	Upper 95% <i>CB</i>
Present	1989-2005	14.798	13.379	16.216
RCP4.5	2071-2087	14.286	13.141	15.431
	2072-2088	14.470	13.325	15.615
	2073-2089	14.481	13.337	15.626
	2074-2090	13.736	12.627	14.845
	2075-2091	13.286	12.249	14.322
	2076-2092	12.765	11.785	13.745
	2077-2093	12.924	11.901	13.948
	2078-2094	12.952	11.829	14.074
	2079-2095	13.076	11.959	14.193
	2080-2096	13.392	12.266	14.517
	2081-2097	13.555	12.429	14.681
	2082-2098	13.539	12.415	14.664
	2083-2099	13.862	12.678	15.046
	2084-2100	13.799	12.612	14.986
RCP8.5	2041-2057	14.646	13.300	15.993
	2042-2058	14.242	12.919	15.566
	2043-2059	13.870	12.595	15.145
	2044-2060	13.975	12.752	15.198
	2045-2061	13.871	12.621	15.121
	2046-2062	13.976	12.729	15.223
	2047-2063	13.881	12.681	15.081
	2048-2064	14.041	12.821	15.262
	2049-2065	14.203	12.952	15.454
	2050-2066	14.066	12.827	15.306
	2051-2067	13.819	12.559	15.079
	2052-2068	13.595	12.374	14.815
	2053-2069	13.442	12.270	14.613
	2054-2070	13.536	12.377	14.694

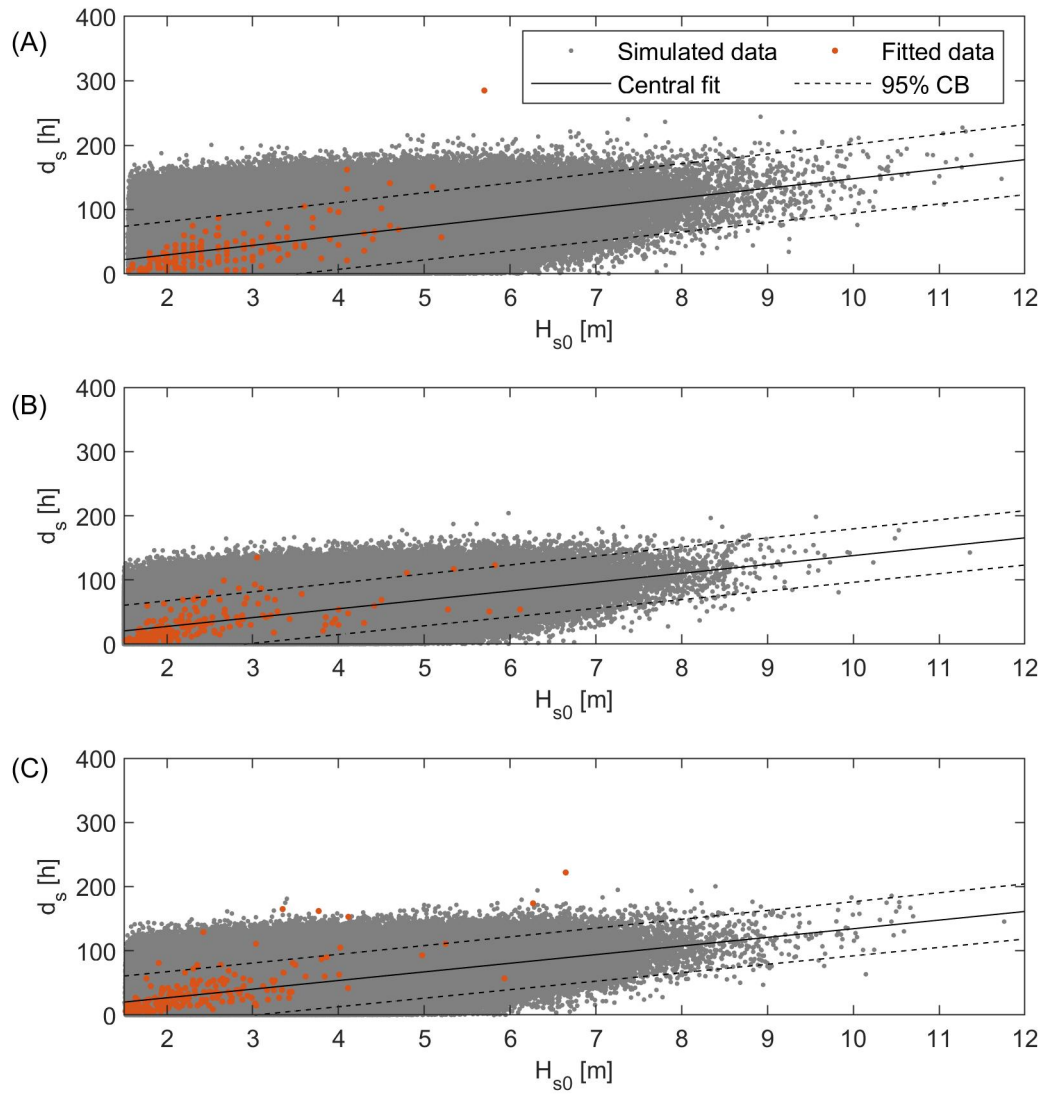


Figure S3. Central fit and 95% confidence bounds of the site-specific empirical relationship between H_{s0} and d_s : (A) (1989-2005); (B) sub-period 2084-2100 under RCP4.5 scenario; (C) sub-period 2053-2069 under RCP8.5 scenario.

Table S4. Estimate and 95% confidence bounds (*CB*) of the coefficient b_{SS} of the site-specific empirical relationship between H_{s0} and d_{SS} defined for present, RCP4.5 and RCP8.5 scenarios

Scenario	Sub-period	Estimate	Lower 95% <i>CB</i>	Upper 95% <i>CB</i>
Present	1989-2005	0.011	0.006	0.015
RCP4.5	2071-2087	-0.006	-0.011	0.001
	2072-2088	-0.005	-0.011	0.001
	2073-2089	-0.005	-0.011	0.001
	2074-2090	-0.004	-0.011	0.002
	2075-2091	-0.003	-0.009	0.004
	2076-2092	0.001	-0.005	0.007
	2077-2093	0.001	-0.005	0.007
	2078-2094	0.002	-0.004	0.008
	2079-2095	0.005	-0.001	0.011
	2080-2096	0.001	-0.005	0.007
	2081-2097	-0.002	-0.008	0.004
	2082-2098	-0.002	-0.008	0.004
	2083-2099	-0.004	-0.010	0.003
	2084-2100	-0.004	-0.010	0.003
RCP8.5	2041-2057	0.001	-0.005	0.008
	2042-2058	0.001	-0.005	0.008
	2043-2059	0.001	-0.006	0.007
	2044-2060	-0.001	-0.007	0.005
	2045-2061	-0.003	-0.010	0.003
	2046-2062	-0.002	-0.008	0.005
	2047-2063	0.000	-0.006	0.006
	2048-2064	0.000	-0.006	0.006
	2049-2065	-0.002	-0.009	0.004
	2050-2066	-0.001	-0.007	0.005
	2051-2067	0.000	-0.006	0.006
	2052-2068	0.001	-0.005	0.007
	2053-2069	0.001	-0.005	0.007
	2054-2070	0.000	-0.006	0.006

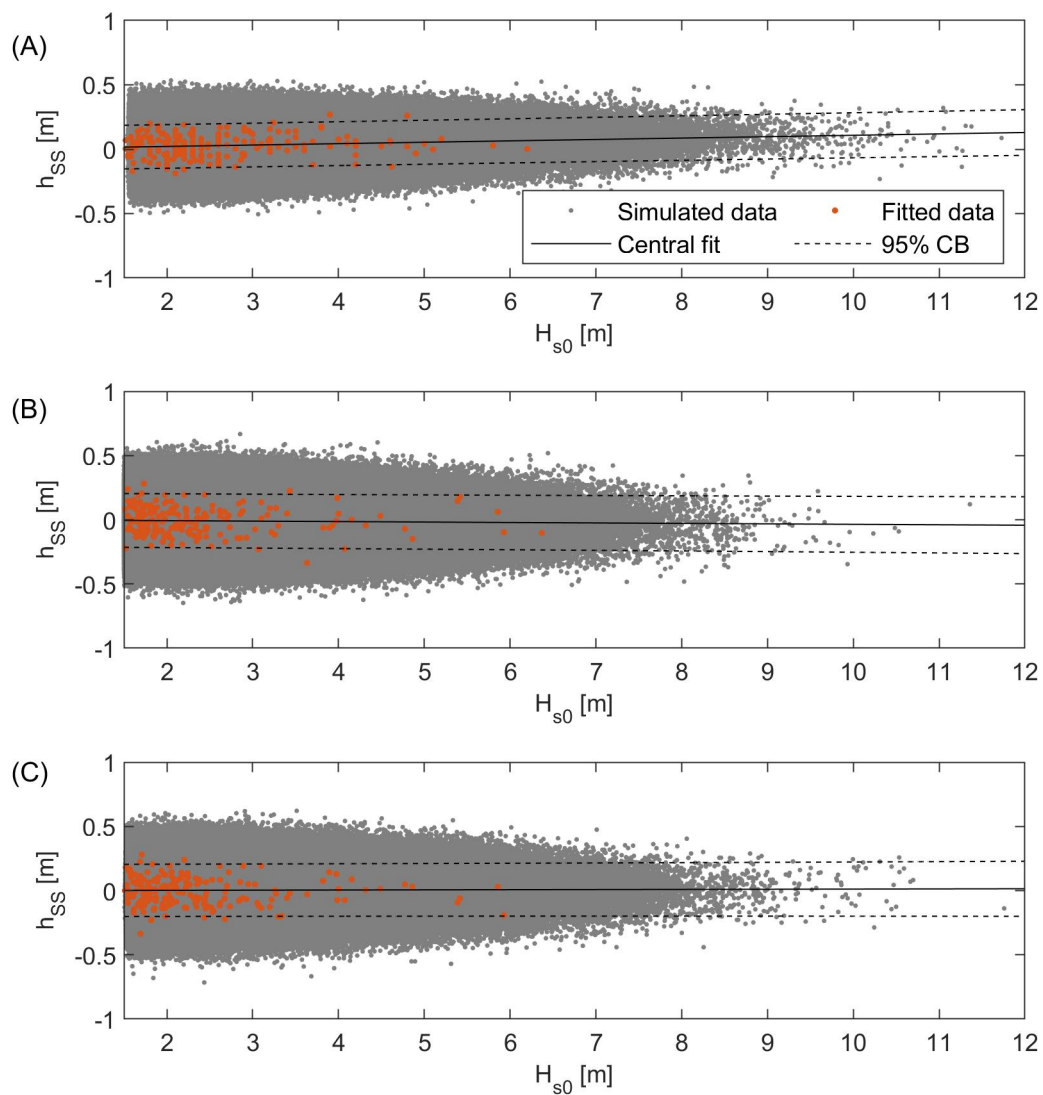


Figure S4. Central fit and 95% confidence bounds of the site-specific empirical relationship between H_{s0} and h_{SS} : (A) (1989-2005); (B) sub-period 2084-2100 under RCP4.5 scenario; (C) sub-period 2053-2069 under RCP8.5 scenario.

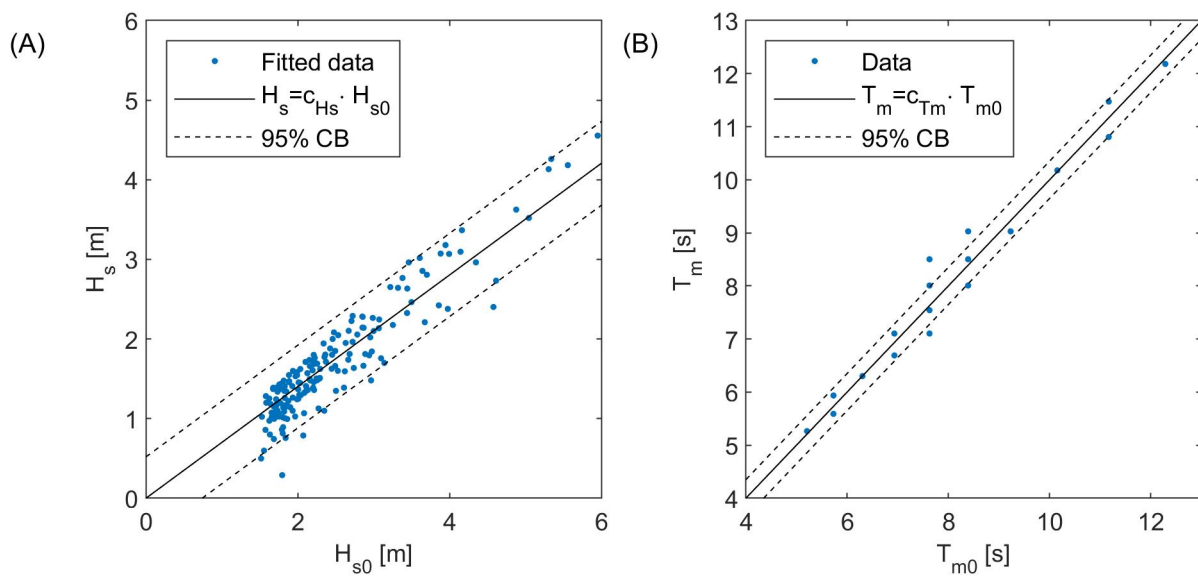


Figure S5. Central fit and 95% confidence bounds of the site-specific empirical formulas for wave propagation towards the breakwater site, which were calibrated using the deep-water significant wave height and mean wave period time series for the years 2006-2019 provided by Korres et al. (2019) and the corresponding values at the breakwater site calculated by the wave model SWAN: **(A)** relationship between the extreme offshore significant wave height (H_{s0}) and the corresponding value at the breakwater site ($c_{H_s}=0.70$, $R^2=0.87$); **(B)** relationship between the extreme offshore mean wave period (T_{m0}) and the corresponding value at the breakwater site ($c_{T_p}=1.00$, $R^2=0.98$).

1.2 Analysis of the convergence of the Monte Carlo simulation outputs

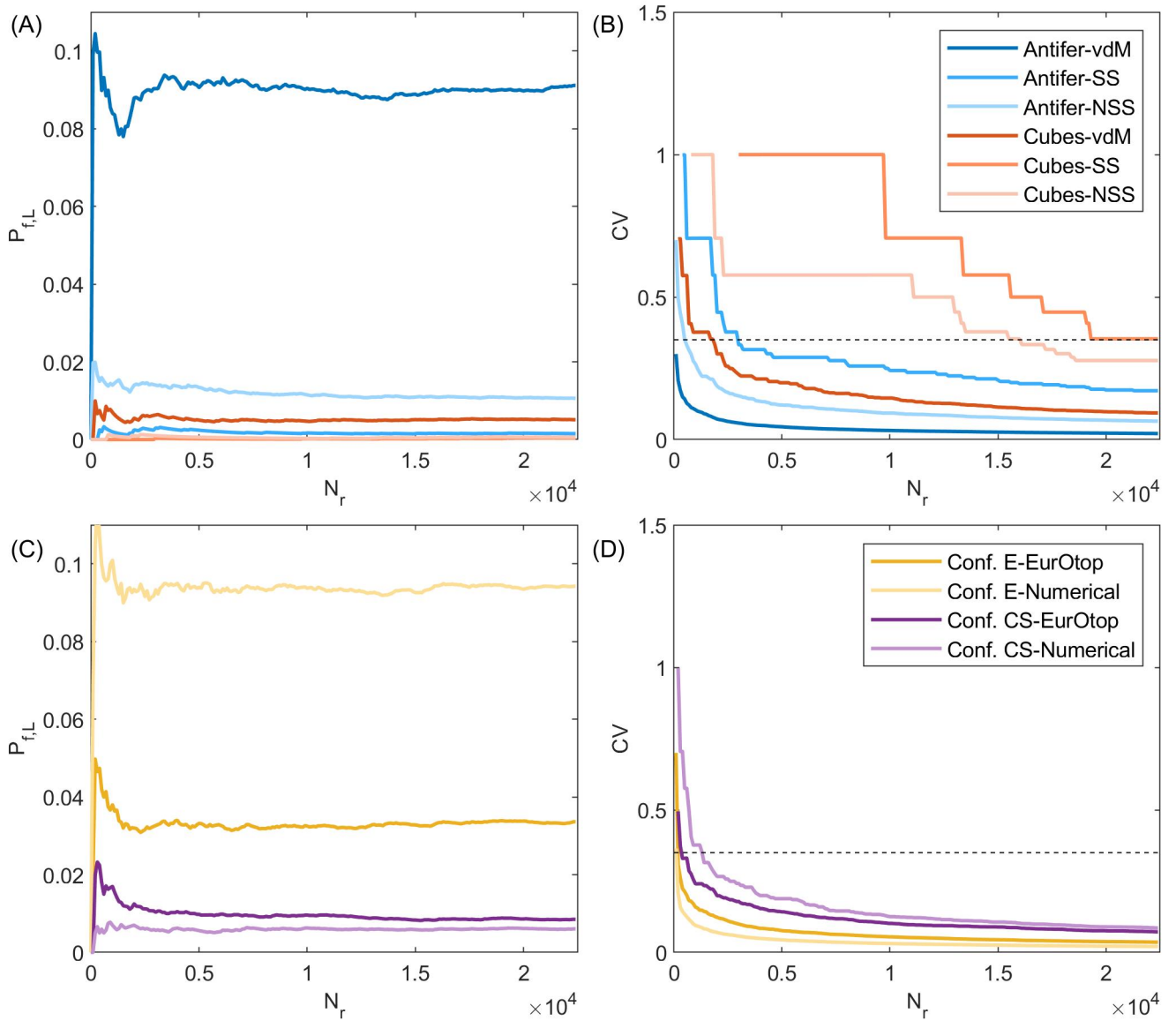


Figure S6. Failure probability during the structure lifetime under present climate expressed as a function of the number of realizations of the MC simulation: **(A)** ultimate limit state (ULS) due to the collapse of the outer armor layer; **(B)** serviceability limit state (SLS) due to excessive mean wave overtopping discharge. Coefficient of variation of the failure probability during the structure lifetime under present scenario expressed as a function of the number of realizations of the MC simulation: **(C)** ULS due to the collapse of the outer armor layer; **(D)** SLS due to excessive mean wave overtopping discharge. The dashed lines indicate the fixed limit $CV=0.35$.