frontiers

Supplementary Material

Visualising the uncertainty cascade in multi-ensemble probabilistic coastal erosion projections

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Ensemble of climate models and dynamic downscaling

IHCantabria (2020) developed dynamic projections of wave conditions and storm surge for the Northeast Atlantic Ocean. The wave and ocean models were forced with the outputs of the following global climate models (GCMs):

GCM	Institution	Country	Atmospheric resolution (latitude x longitude)	Available time periods
MIROC5	MIROC	Japan	1,40º x 1,40º	1985-2005; 2026-2045; 2081-2100
IPSL-CM5A	Institut Pierre-Simon Laplace	France	1,25º x 1,25º	1985-2005; 2026-2045; 2081-2100
CNRM-CM5	Centre National de Recherches Météorologiques	France	1,40º x 1,40º	1985-2005; 2006-2100
CMCC-CM	Centro Euro-Mediterraneo per I Cambiamenti Climatici	Italy	0,75º x 0,75º	1985-2005; 2026-2045; 2081-2100
ACCESS1	CSIRO-BOM	Australia	1,25º x 1,90º	1985-2005; 2006-2100
HadGEM2-ES	Met Office Hadley Centre	UK	1,25º x 1,90º	1985-2005; 2026-2045; 2081-2100

Table S1. Summary of the GCMs used in the dynamic simulations.

Bias correction

The PDF_{score} measures the degree of similarity of two probability density functions, allowing to compare entire time series without the limitation of having non-simultaneous climatic data over time. We discretized and smoothed the "observed" and simulated empirical distribution functions using the Kernel method, which enables the non-parametric estimation of density functions. We compare the "observed" and simulated probability functions interval to interval, keeping the minimum pair of values of the density function for every interval. The PDF_{score} is calculated as the sum of these pairs:

$$PDF_{score} = \frac{1}{n}\sum_{i=1}^{n} \min(PDF_{obs}, PDF_{mod}) \quad (S1)$$

where n is the total number of intervals in which the significant wave height and storm surge are discretized and PDF_{obs} and PDF_{mod} are the probability distribution functions smoothed by means of the Kernel method of observations (reanalysis CFSR data) and the simulations (data from the GCMs). The PDF_{score} reaches a value equal to 1 when the functions are similar and 0 when there is no overlap between them.

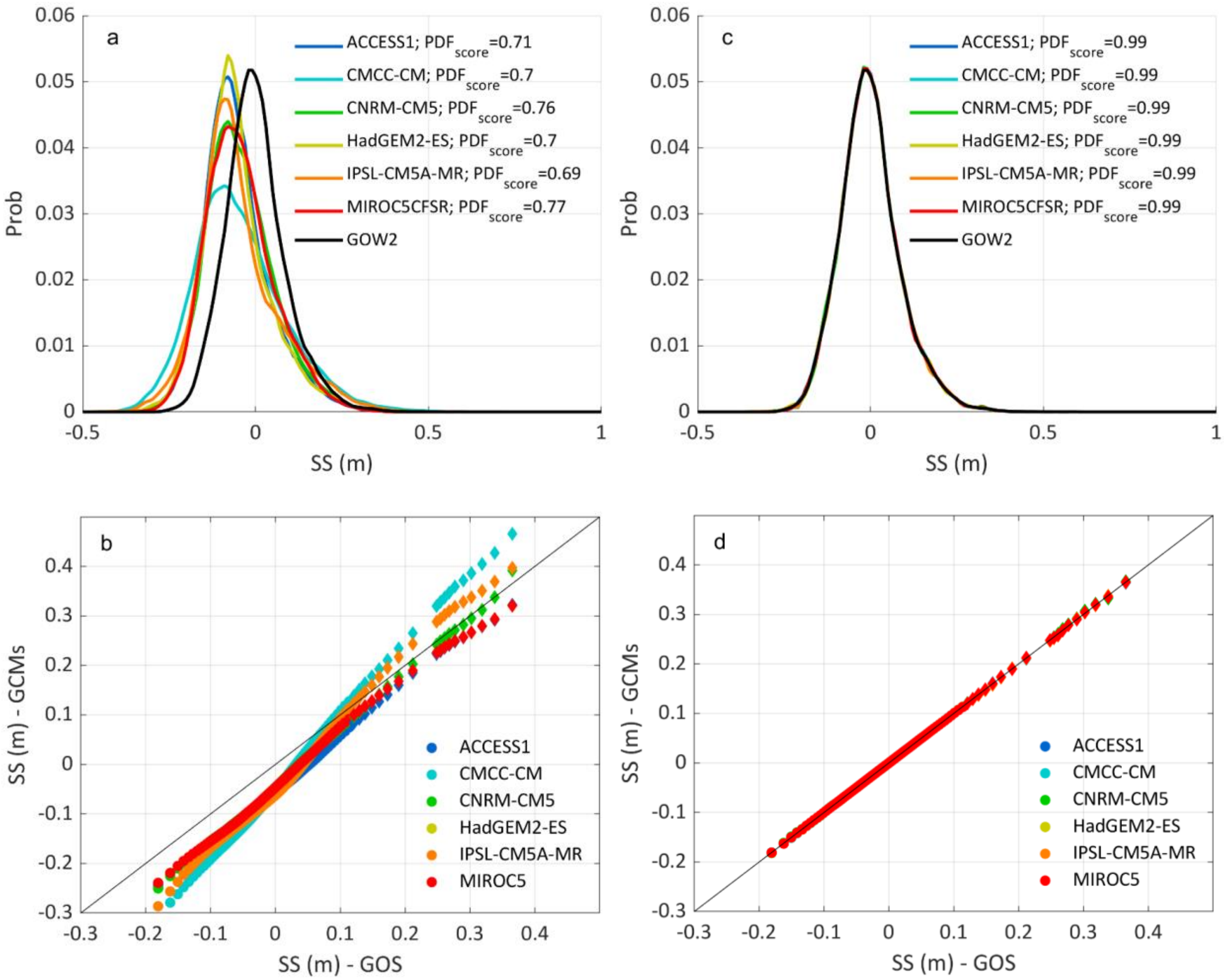

Figure S1. a) Probability distribution function of storm surge at deep waters from the GOS database and the uncorrected climatic data from each ensemble member (i.e., ACCESS1.0, CMCC-CC, CNRM-CM5, HadGEM2-ES, IPSL-CM5A-MR, MIROC5) with the corresponding PDFscore. b) Q-Q plot of the original uncorrected and corrected storm surge, per ensemble member. c) Probability distribution functions of GOS storm surge and corrected storm surge from each ensemble member. d) Q-Q plot of the original uncorrected SS, per ensemble member.

Supplementary Material for *Visualising the uncertainty cascade in multi-ensemble probabilistic coastal erosion projections*

Hybrid downscaling of wave projections

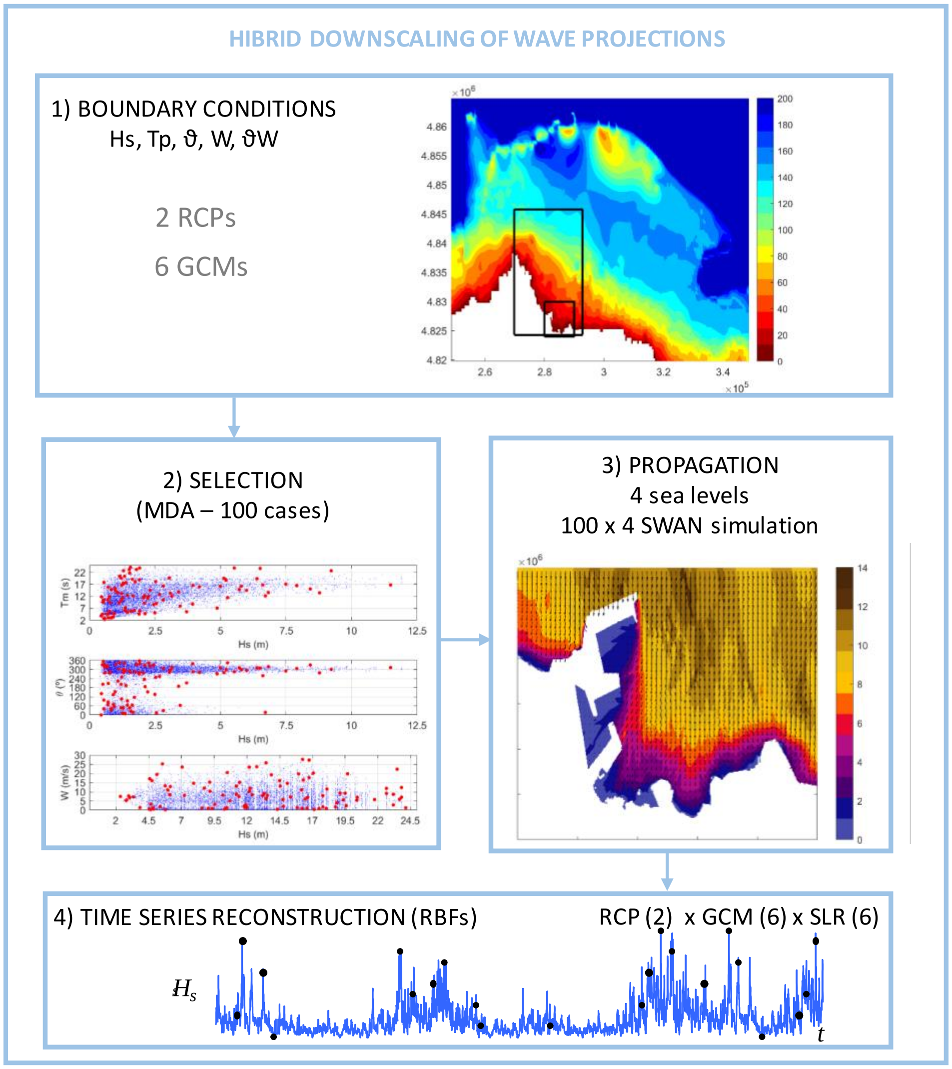

Figure S2. Steps of methodology of hybrid downscaling of wave projections.

<u>Generation of multivariate synthetic time series</u>

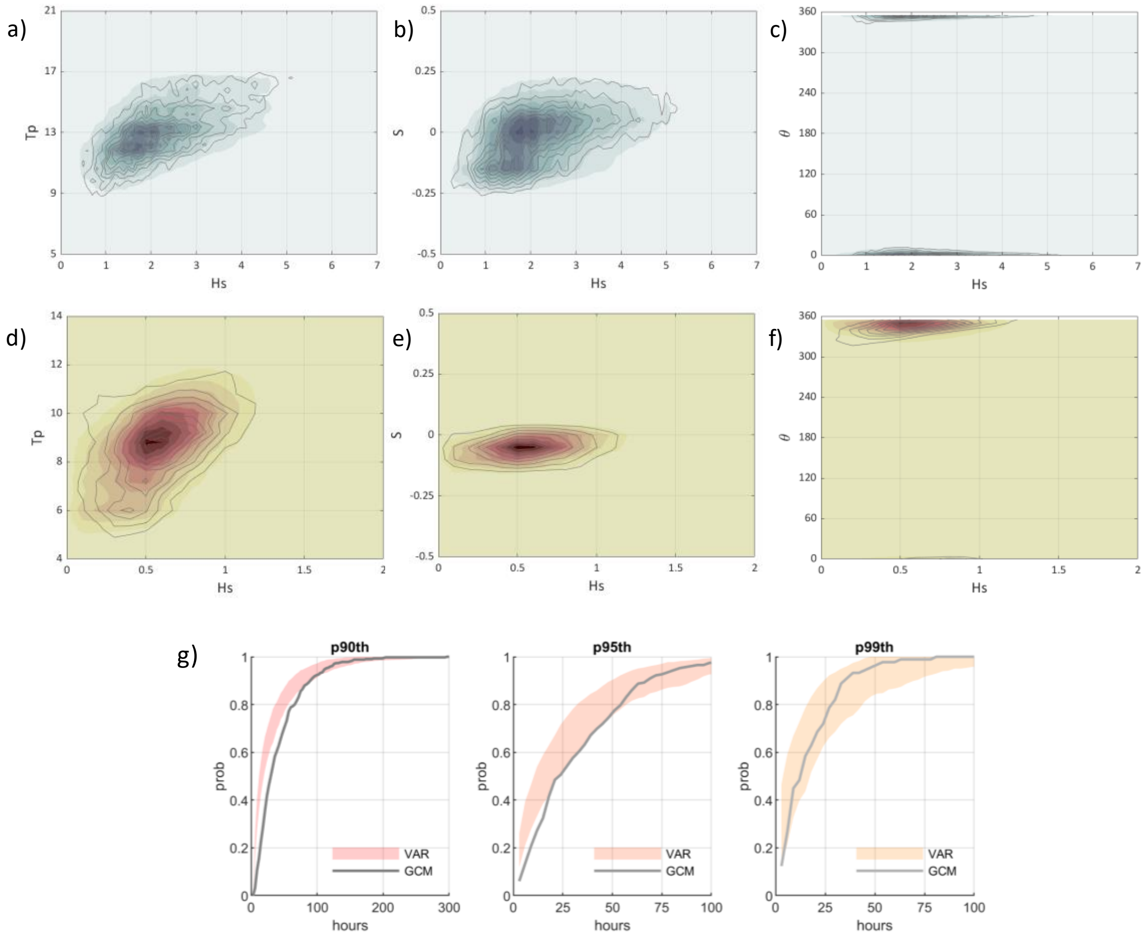

Figure S3. Validation of the VAR model in the historical period (1985-2002) for the IPSL-CM5A-MR model. a-d) Hs-Tp joint probability distribution in winter and summer, respectively. b-e) Hs-Storm surge joint probability distributions in winter and summer. c-f) Hs-Storm surge joint probability distribution in winter and summer. Solid lines represent GCM data. Shaded contour plot represents simulated data using VAR. g) Distribution of persistence over several thresholds: 90^{th}, 95^{th} and 99^{th} percentiles. Solid line represents GCM data. Shaded areas (99% confidence intervals) represent simulated data using VAR.

The cascade of uncertainty

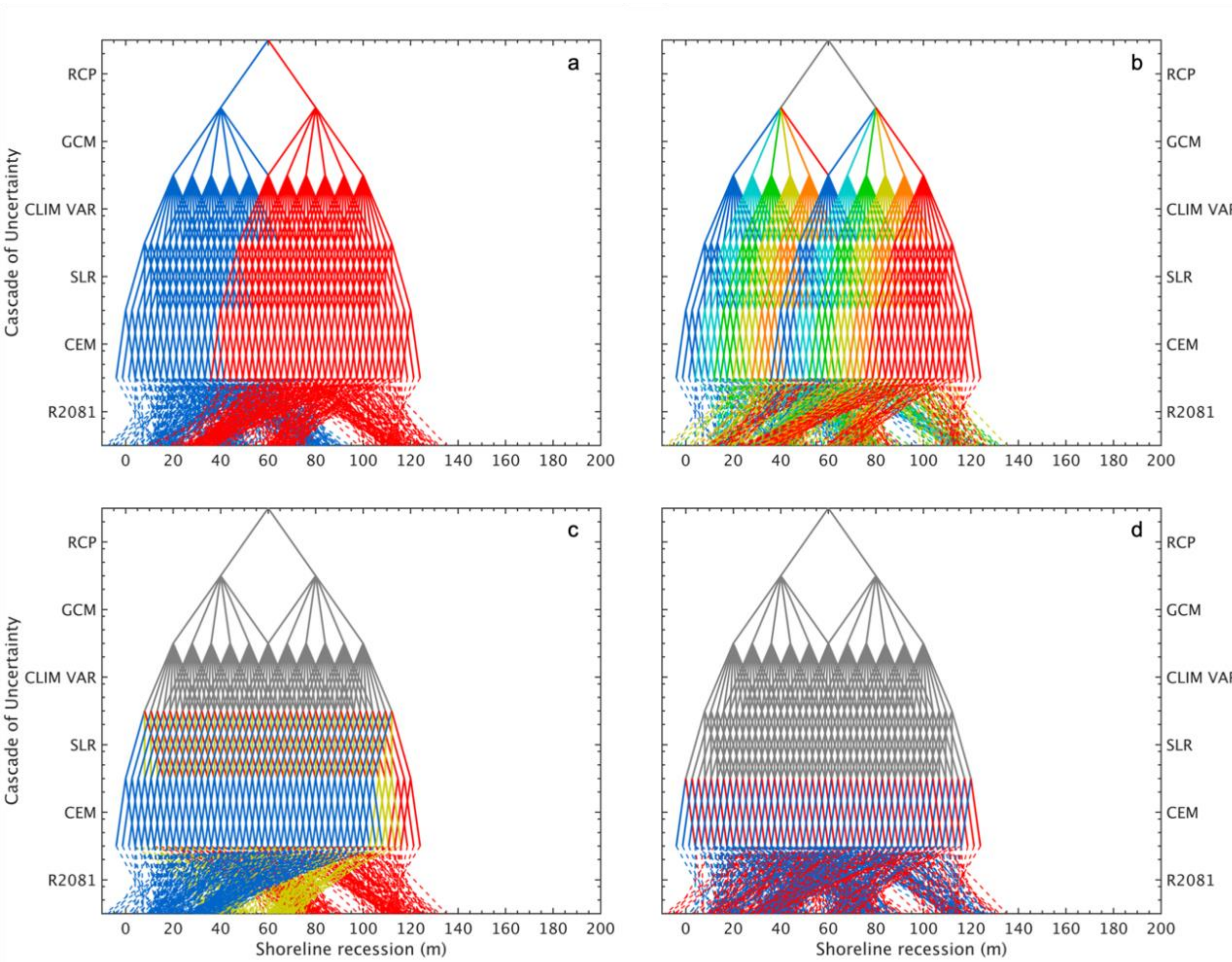

Figure S4. Visualisation of the cascade of uncertainty in coastal erosion projections by 2100. The cascade is built upon SP1 simulations. From top to bottom: first layer shows the 2 RCPs, second layer shows the ensemble of 6 GCMs, third layer shows climate variability, fourth layer shows the 3 SLR percentiles, fifth layer shows the ensemble of 2 CEMs and the last layer shows the R2100 indicator (actual values displayed on the horizontal axis). Panels a-d illustrate the cascade under four factorisations that highlight the uncertainty spread due to the choice of RCPs, GCMs (considering climate variability realisations), SLR percentiles, and CEMs. For the sake of visibility, we plot 720 SP1 simulations (out of 72,000) covering the full range of 2100 and distribute RCP, GCM, CLIM VAR, SLR and CEM levels evenly in space.

Factorisation of uncertainty sources

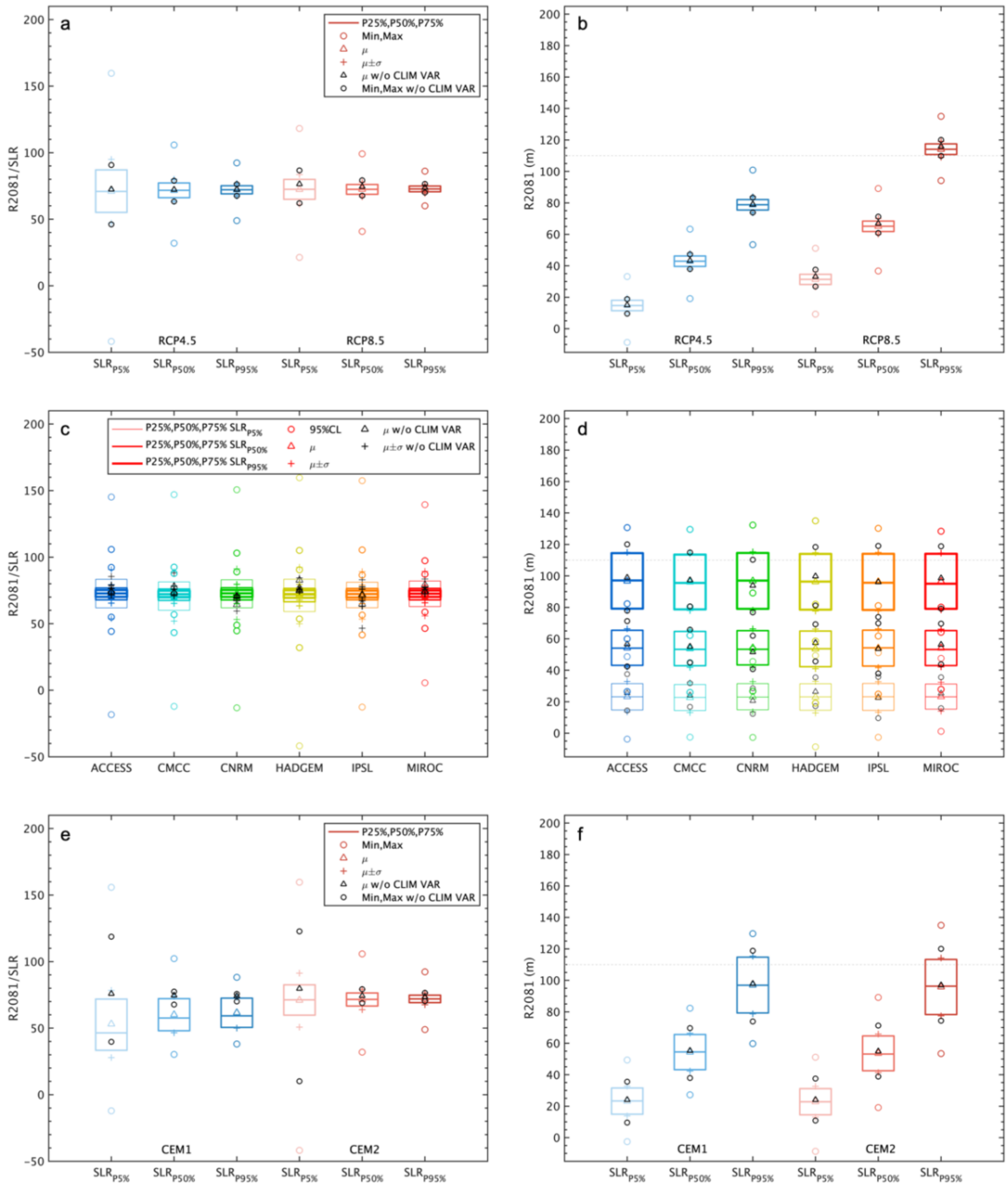

Figure S5. R2081 values factorised by their driving RCPs (panels a and b), GCMs (panels c and d) and CEMs (panels e and f), all of them disaggregated in turn by the SLR percentiles (5th, 50th and 95th). R2100 factorisation is provided in absolute terms (m) on the right column and nondimensionalised by SLR on the left column. SP1 (72,000 simulations considering climate variability) and SP3 (72 simulations without considering climate variability) are represented using coloured and black symbology, respectively. Note that in panels b, d and f the grey dashed line represents the threshold beyond which the beach would have disappeared.

Non-stationary extreme value analysis and influence of climate variability

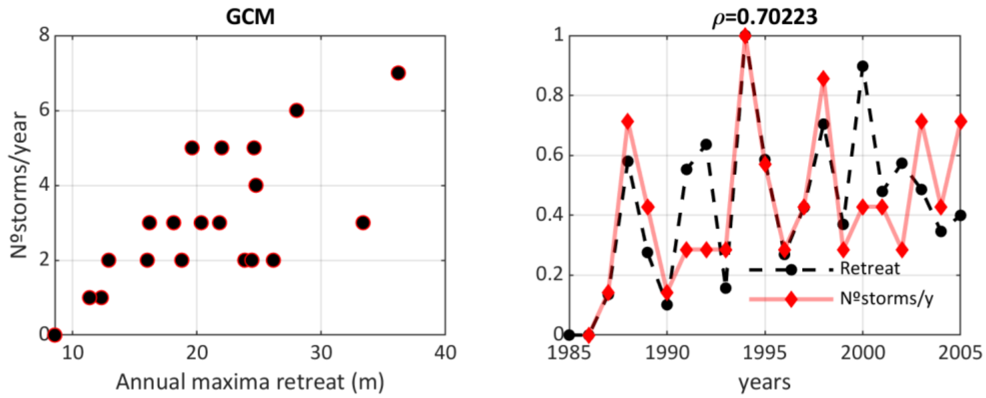

Figure S6. Scatter plot of the annual maxima shoreline retreat compared to the annual number of storms. Time series of the normalised annual maxima shoreline retreat and normalised annual number of storms for the simulations of the original IPSL-CM5A-MR run in the historical period (1985-2005).

References

IHCantabria (2020). High-resolution projections of waves and water levels along the Spanish coast. Spanish Ministry for the Ecological Transition and the Demographic Challenge, 60 pages (in Spanish).