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Projections of changes in extreme storm surges for European coasts using statistical downscaling

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Supplementary Materials

Table S1 CMIP6 global climate models employed for ensemble storm surge projections. Zonal and meridional winds at 10-meters are available at 3-hourly frequency, while atmospheric pressure is available at 6-hourly frequency, except for the MPI models which provide 3-hourly frequency.

CMIP6 model	Resolution (lon x lat, *degrees*)
MPI-ESM1-2-HR	0.9375 x 0.9375
CNRM-CM6-1-HR	0.5 x 0.5
EC-Earth3	0.7 x 0.7
HadGEM3-GC31-MM	0.833 x 0.556
BCC-CSM2-MR	1.125 x 1.125
CMCC-CM2-SR5	1.25 x 0.9375
KIOST-ESM	1.875 x 1.875
MIROC6	1.4 x 1.4
NESM3	1.875 x 1.875
MRI-ESM2-0	1.125 x 1.125
CMCC-ESM2	1.4x1.4
HadGEM3-GC3-LL	1.875 x 1.25
ACCESS-CM2	1.9 x 1.3
IPSL-CM6A-LR	1.25 x 2.5
CNRM-CM6-1	1.4 x 1.4
MIROC-ES2H	1.4 x 1.4
MPI-ESM1-2-LR	1.875 x 1.875

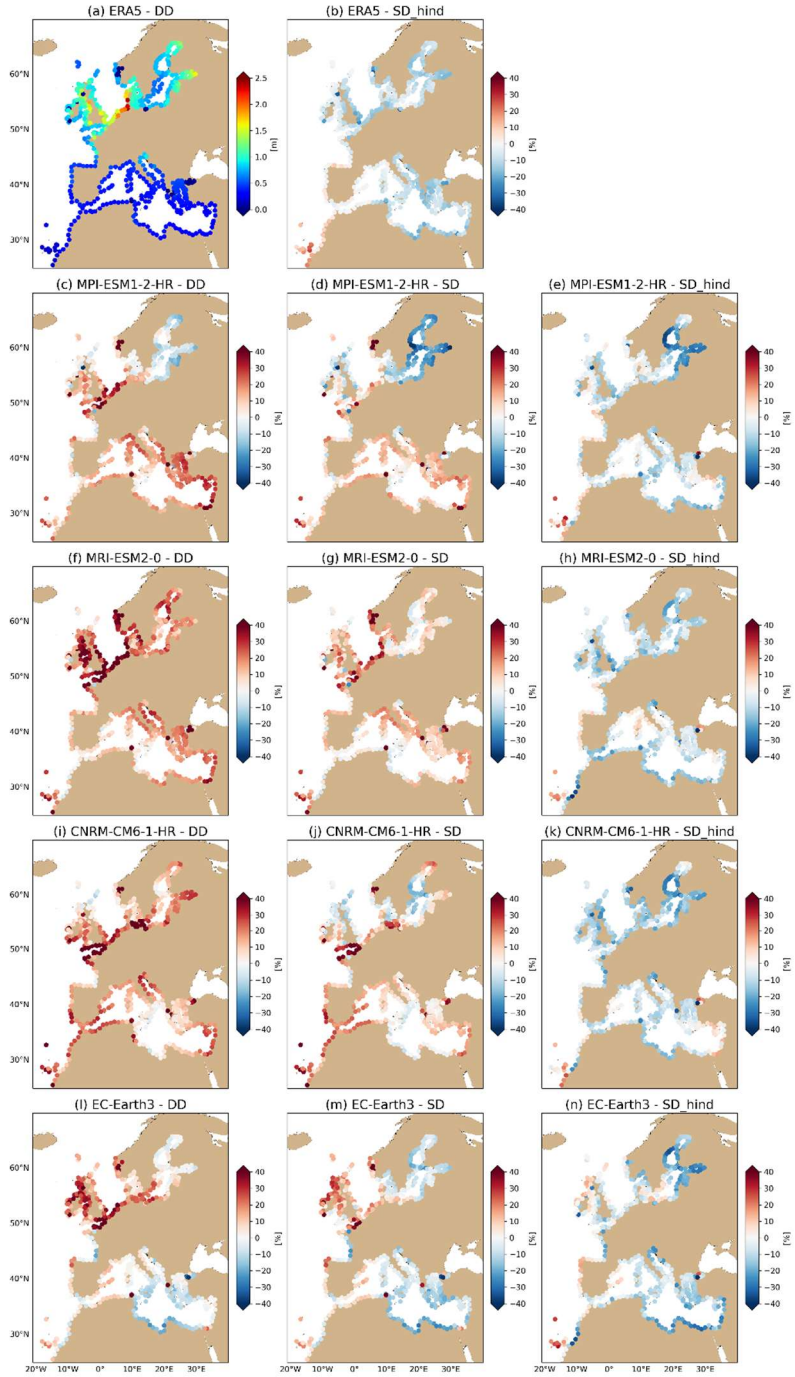


Figure S1 Validation against the hindcast dynamical simulation (panel a) of the 10-year storm surge return level from historical storm surge climate simulations: using the dynamical ensemble (c,f,i,l), using the statistical downscaling model (SDM) trained in the historical period for each GCM (d,g,k,m) and the SDM trained in the hindcast simulation (e,h,k,n). All pannels indicate relative differences [%] with the hindcast (panel a). Return levels are derived via stationary extreme value analysis on 1995-2014 for all experiments except for the dynamically downscaled hindcast, for which a slightly different 20-yr period is used based on the simulation coverage (1997-2016). The SDM reconstruction of the hindcast simulation (b) is added for reference.

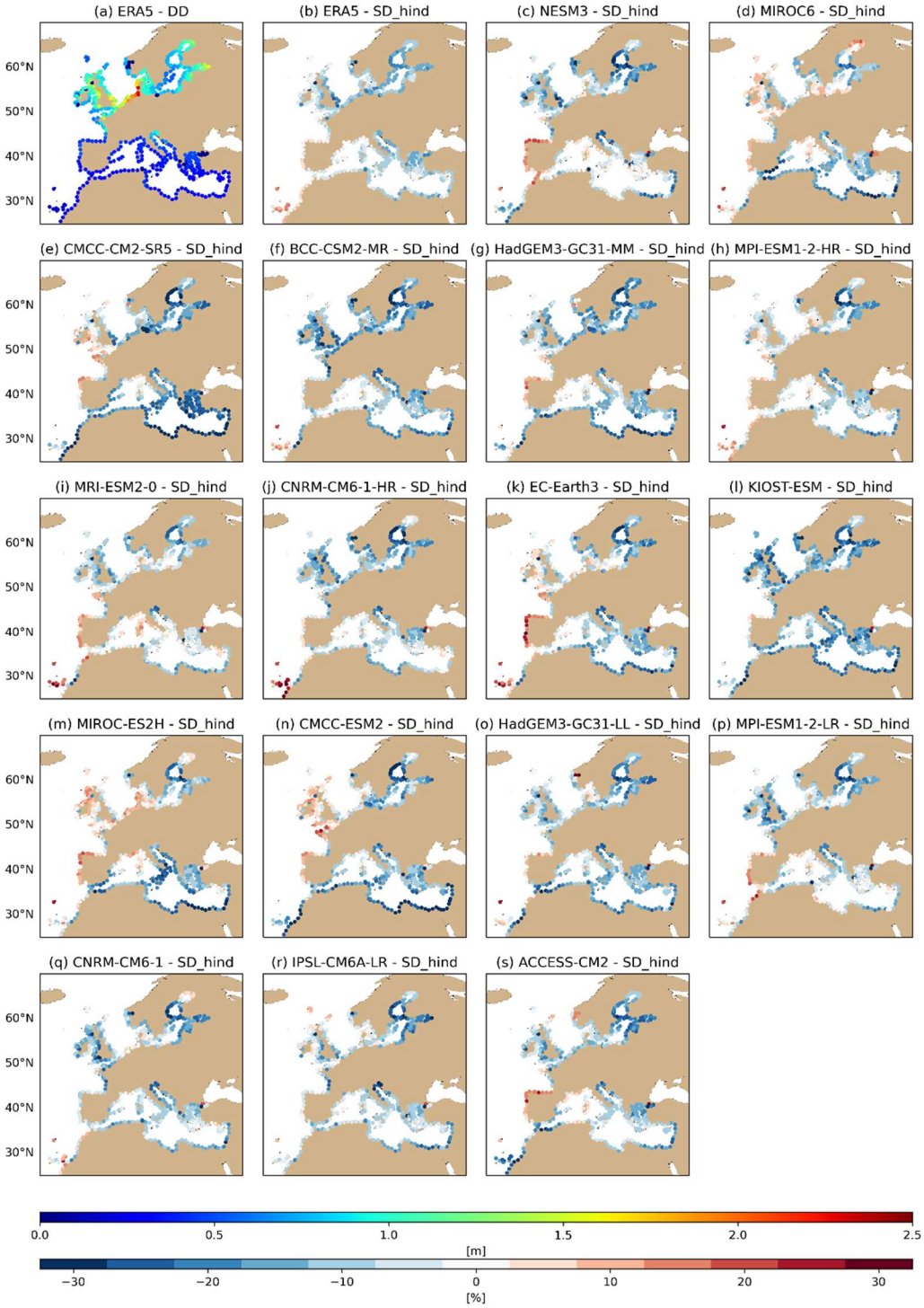


Figure S2 Validation against the hindcast dynamical simulation (a) of the 10-year storm surge return level (stationary EVA on 30 years, 1985-2014) from statistical storm surge estimates for historical climates for each GCM in the 17-model ensemble. All pannels indicate relative differences [%] relative to the hindcast (a).

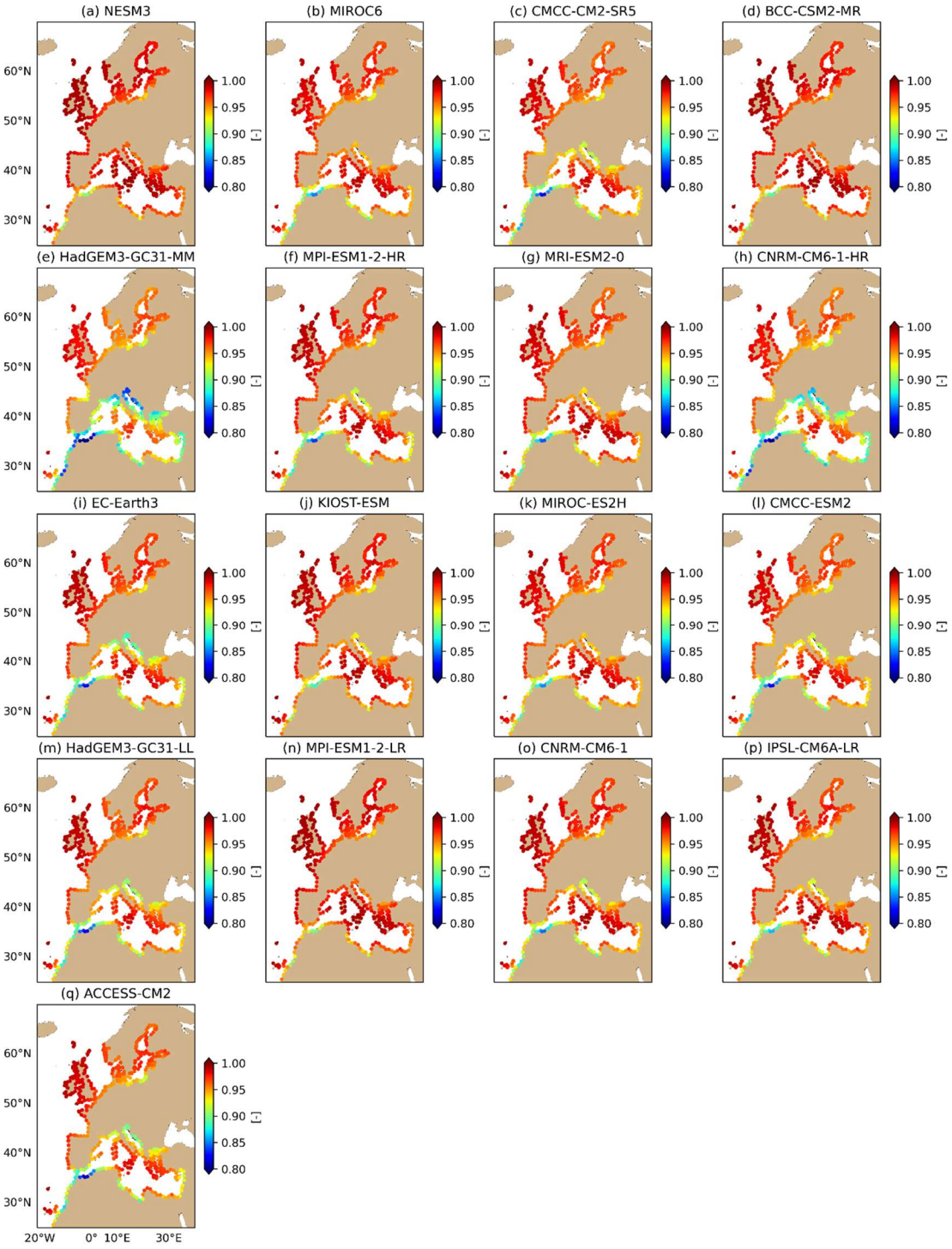


Figure S3 Explained total variance in the period 1995-2014 by the principal components resulting from the projection of the bias-corrected CMIP6 GCM atmospheric fields onto the empirical orthogonal functions (EOF) identified from training the statistical downscaling model on the hindcast simulation (*SD_hind*, i.e. EOFs extracted for the ERA5 reanalysis in 1997-2021).

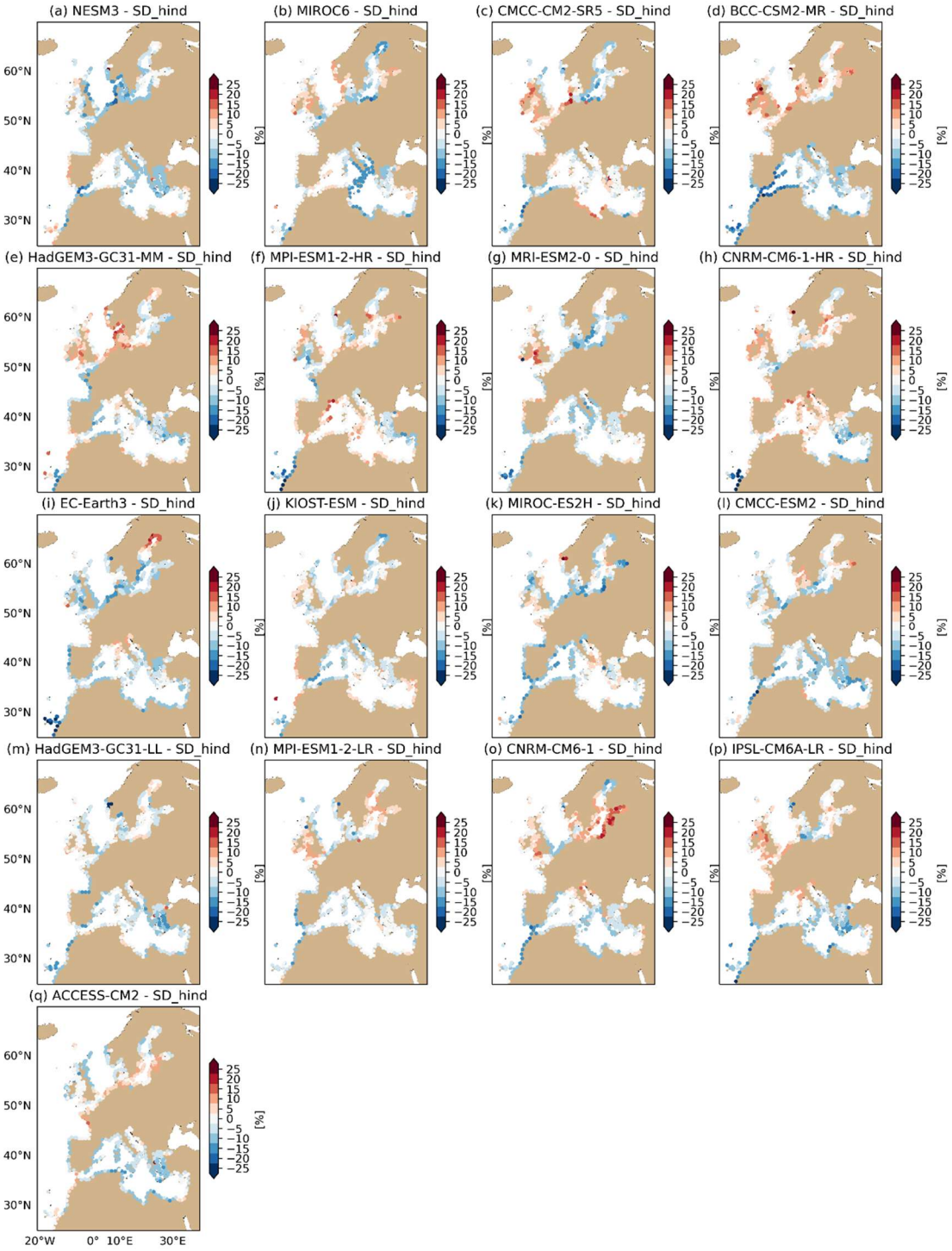
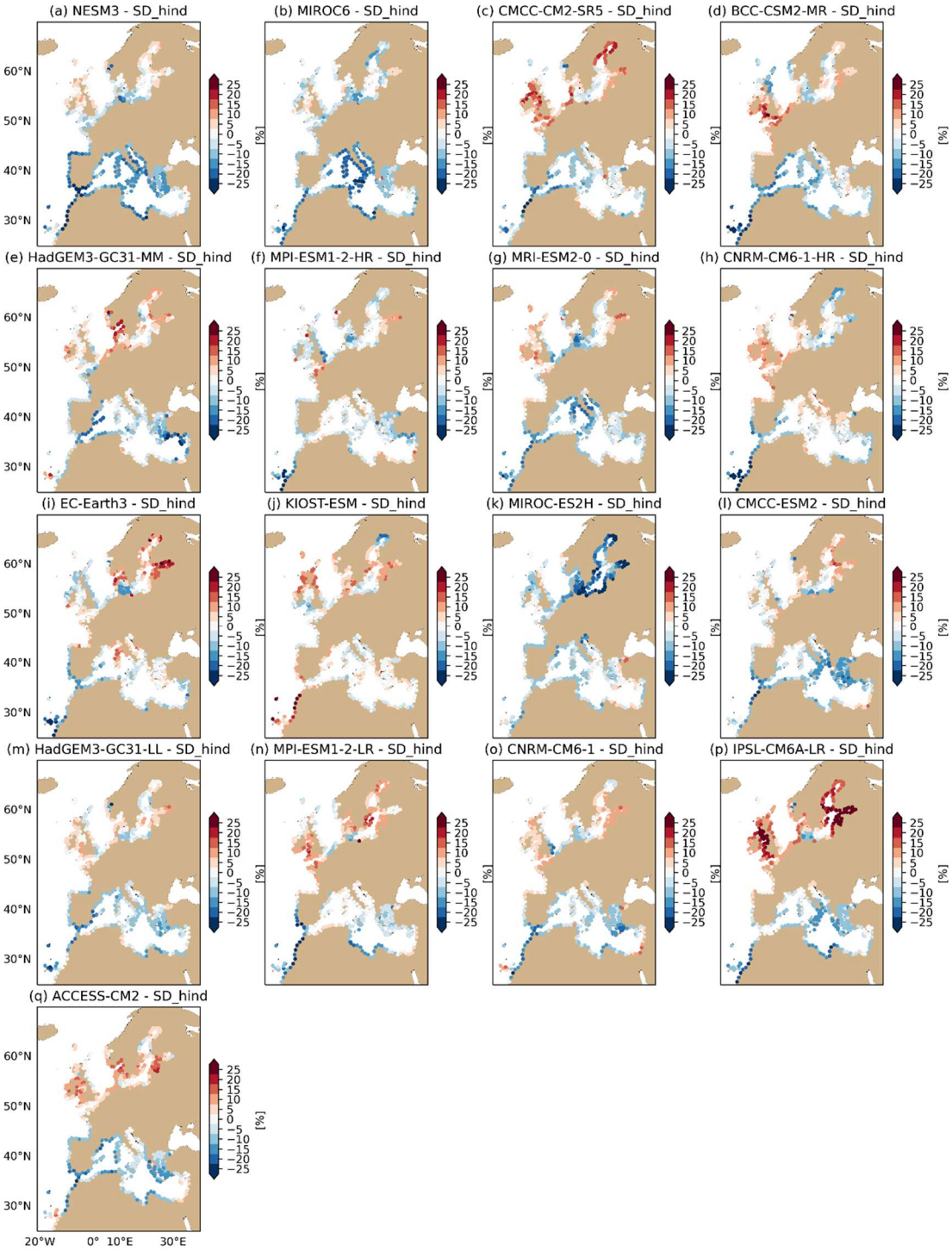


Figure S4 Projections of changes [%] in the storm surge 10-year return level for the middle of the 21st century (stationary extreme value analysis on [2035-2064] vs [1985-2014]) for each of the 17 GCM models in the ensemble.



25 **Figure S5 Projections of changes [%] in the storm surge 10-year return level for the end of the 21st century (stationary extreme value analysis on [2070-2099] vs [1985-2014]) for each of the 17 GCM models in the ensemble.**

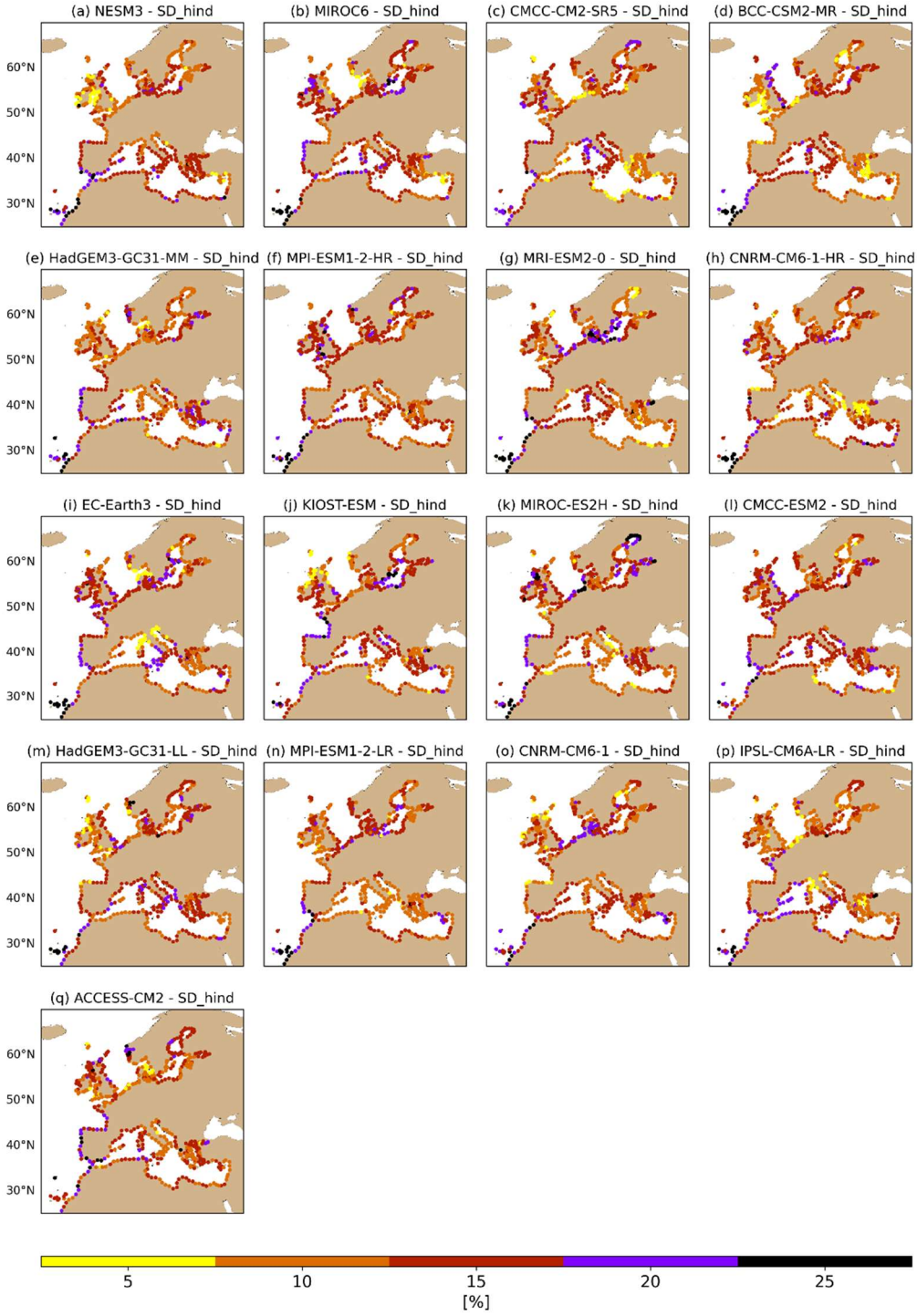


Figure S6 Relative confidence interval (95th – 5th percentiles) for the 10-year storm surge return level in the historical climate (stationary extreme value analysis on 1985-2014) for each of the 17 GCM models in the statistical ensemble. Confidence intervals are produced using mean-adjusted bootstrap with replacement (600 iterations).

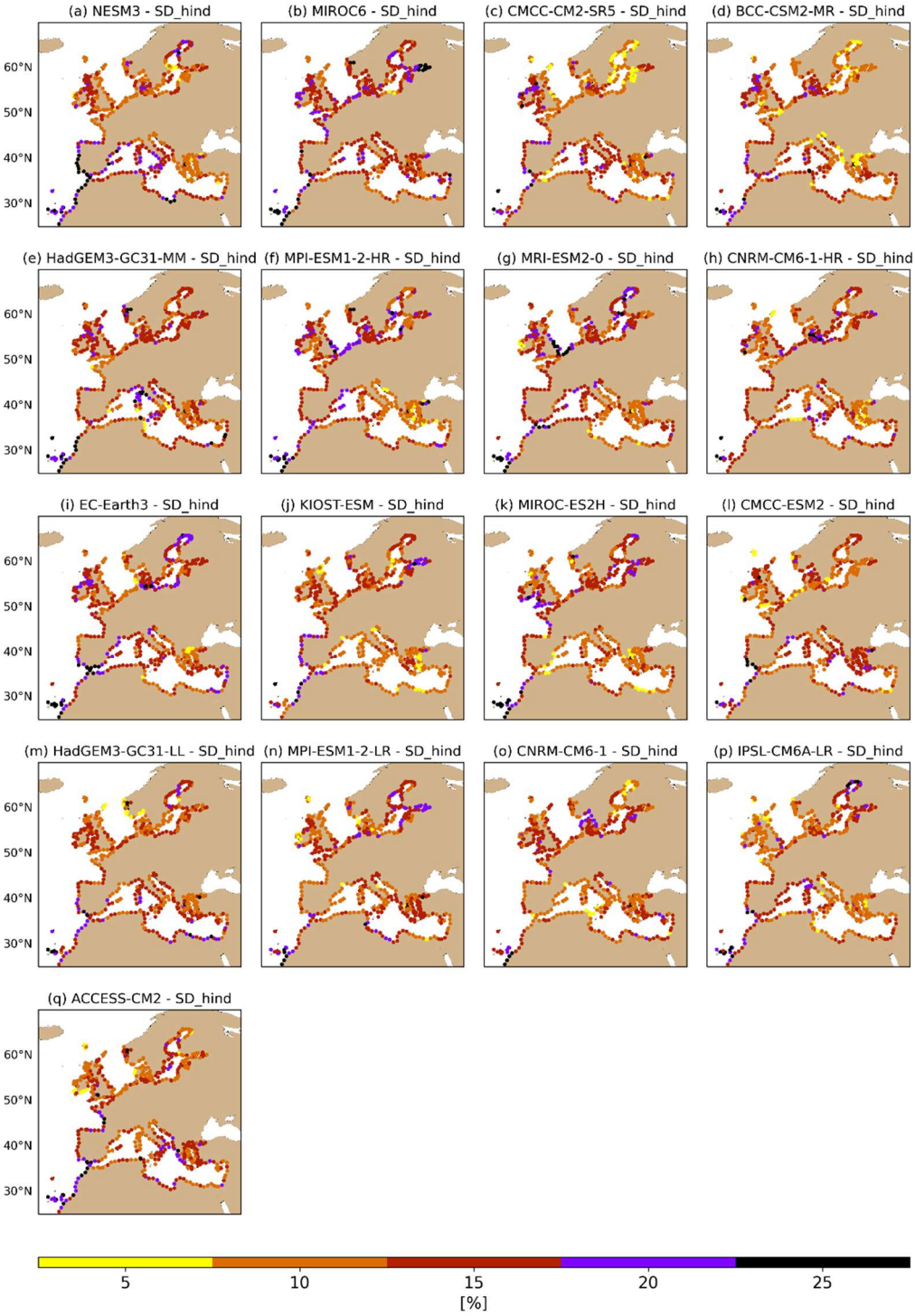


Figure S7 Relative confidence interval width (95th – 5th percentiles, %) for the 10-year storm surge return level in the middle of the 21st century for SSP5-8.5 (stationary extreme value analysis on 2035-2064) for each of the 17 GCM models in the statistical ensemble. Confidence intervals are produced using mean-adjusted bootstrap with replacement (600 iterations).

Figure S8 Relative confidence interval width (95th – 5th percentiles, %) for the 10-year storm surge return level in the end of the 21st century for SSP5-8.5 (stationary extreme value analysis on 2070-2099) for each of the 17 GCM models in the statistical ensemble. Confidence intervals are produced using mean-adjusted bootstrap with replacement (600 iterations).

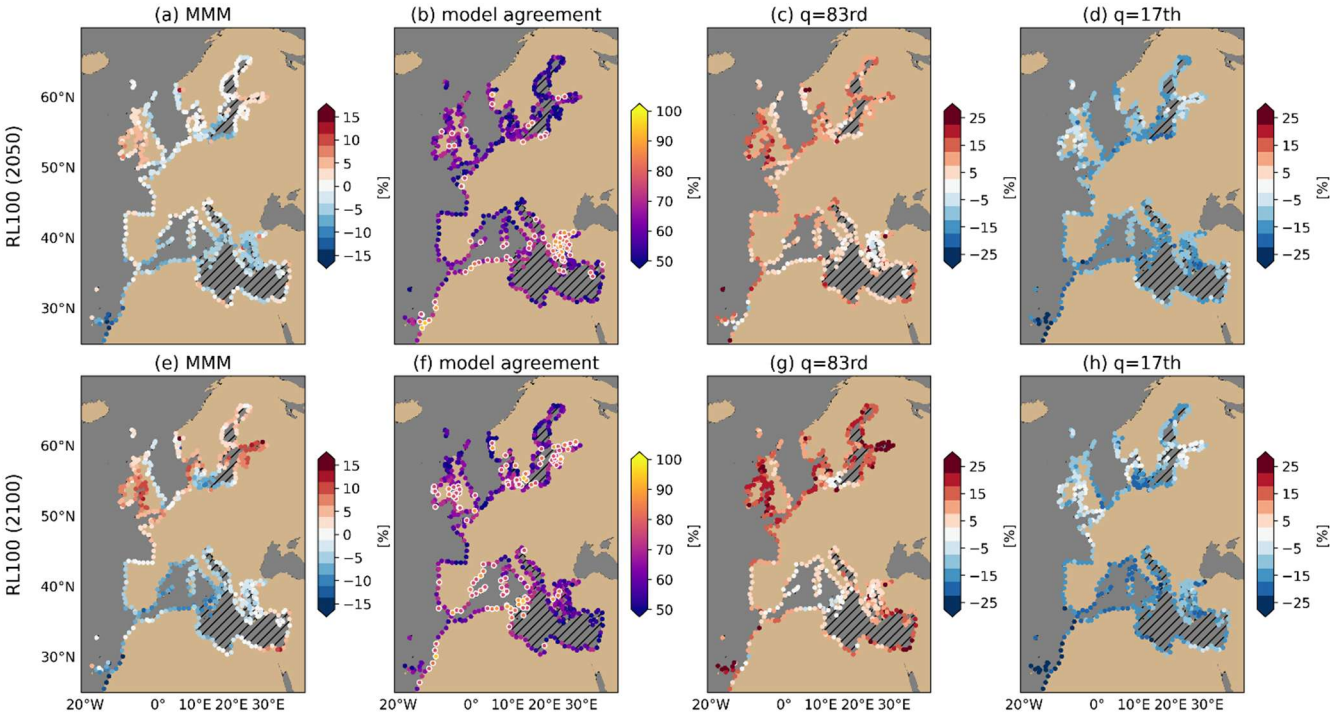
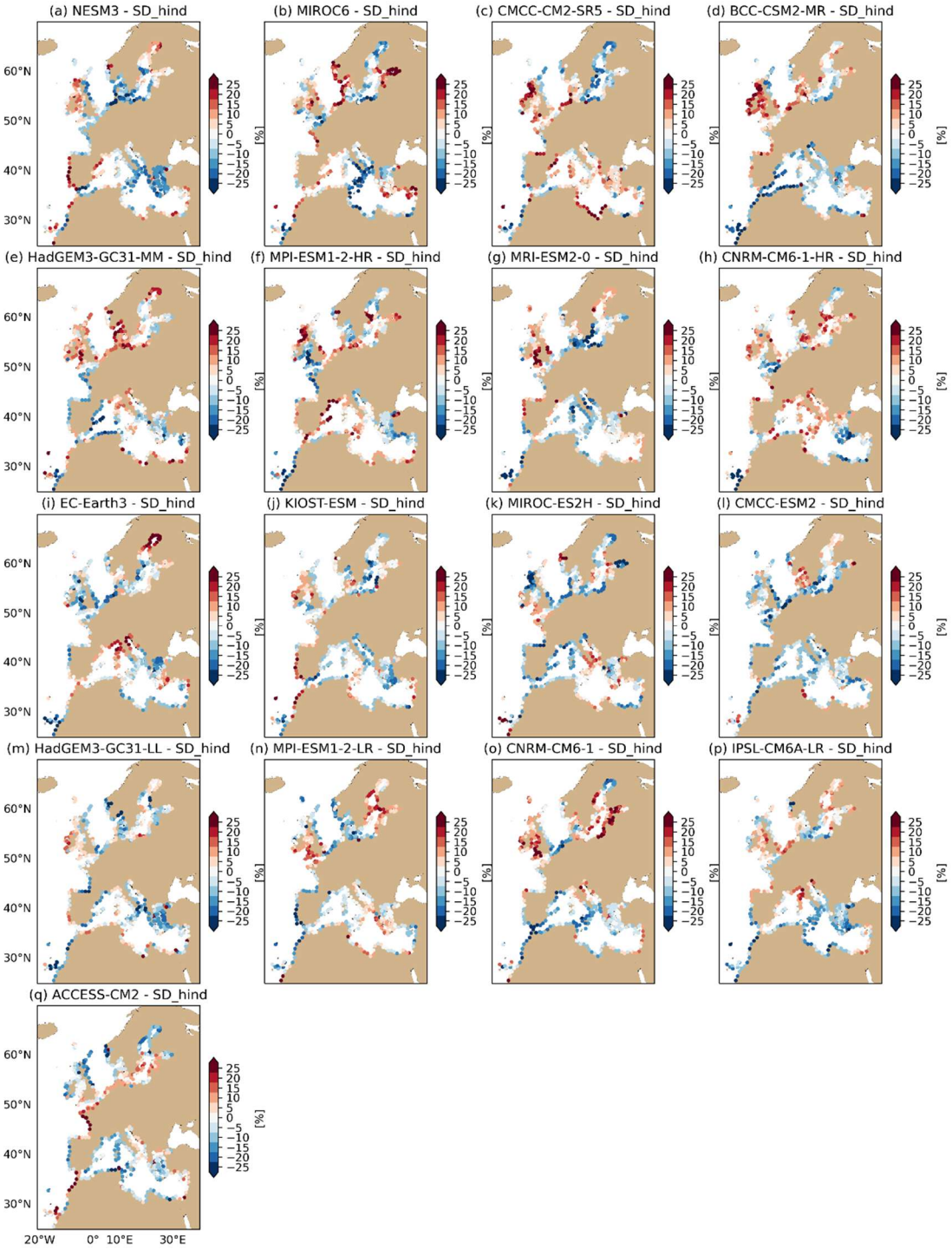


Figure S9 Muti-model mean (MMM) projected changes [%] in the 1 in 100 storm surge return level by middle (a) and end (e)-of the 21st century generated by the hindcast-trained statistical downscaling model (SDM, training period 1997-2021). Corresponding ratio of models agreeing in the sign of projected changes (b, f), 83rd (c, g) and17th (d, h) percentiles, indicating the likely range as per IPCC definitions. Hatching over the eastern Mediterranean Sea and the Baltic Sea indicate lower confidence in statistical projections in these regions given limited skill of the SDM for both past and future extreme storm surges. Extreme value analysis is computed for 30-year periods: baseline [1985-2014], middle of the century [2035-2064], and end of the century [2070-2099]. For reference, in a 17-model ensemble, the 17th and 83rd quantiles correspond to the lower/higher ~3 models. The % model agreement represents confidence in the sign of projected changes. Those with ratio >80% (here, >=13/17 models) are marked with white circle edges in panels (b,f).



50 **Figure S10 Projections of changes [%] in the storm surge 100-year return level for the middle of the 21st century (stationary extreme value analysis on [2035-2064] vs [1985-2014]) for each of the 17 GCM models in the ensemble.**

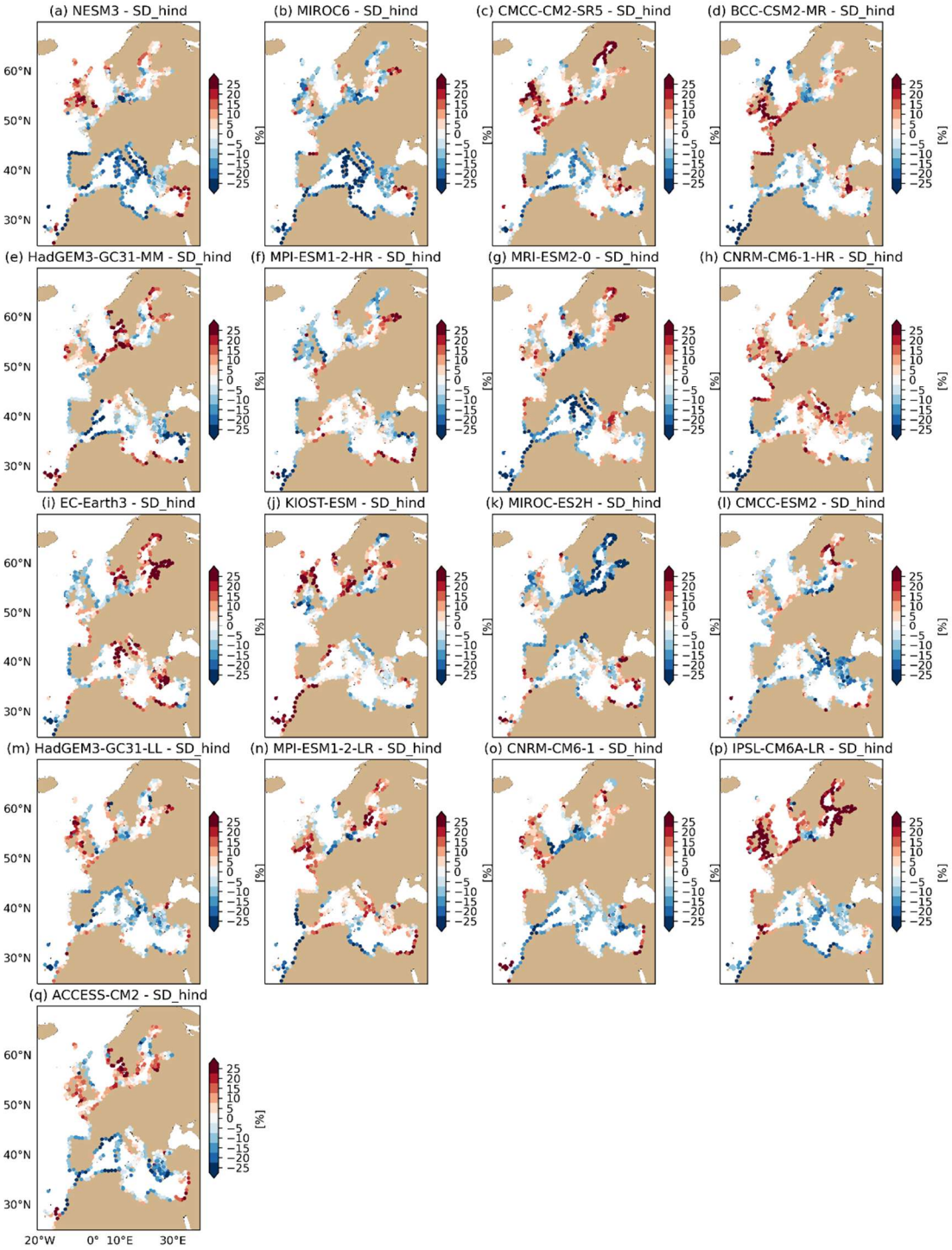


Figure S11 Projections of changes [%] in the storm surge 100-year return level for the end of the 21st century for SSP5-8.5 (stationary extreme value analysis on [2070-2099] vs [1985-2014]) for each of the 17 GCM models in the ensemble.