Supplementary Materials for

Title: Seasonal forecasting of subsurface marine heatwaves

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Figs. S1 to S8

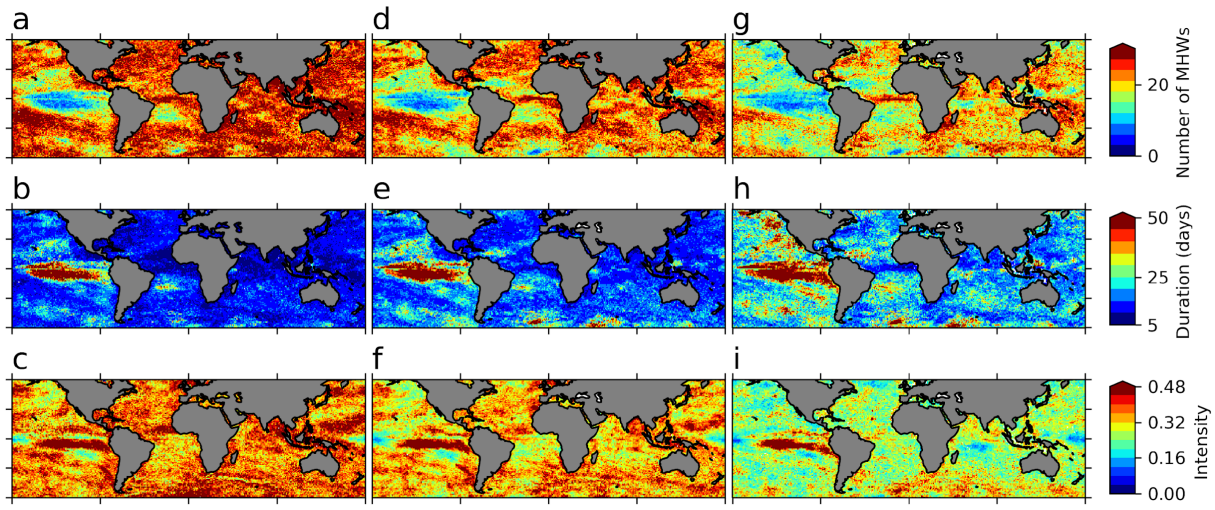

Fig. S1. Average summer marine heatwave (MHW) characteristics. Total number (top row: a,d,g), average duration (middle row: b,e,h) and normalised intensity (bottom row: c,f,i) of summer MHWs over the 1993-2016 period in ESA CCI SST observations (left column), GREP SST middle column) and GREP OHC 0-40m (right column). All scores correspond to the hemisphere-specific summer season and the 1993-2016 period.

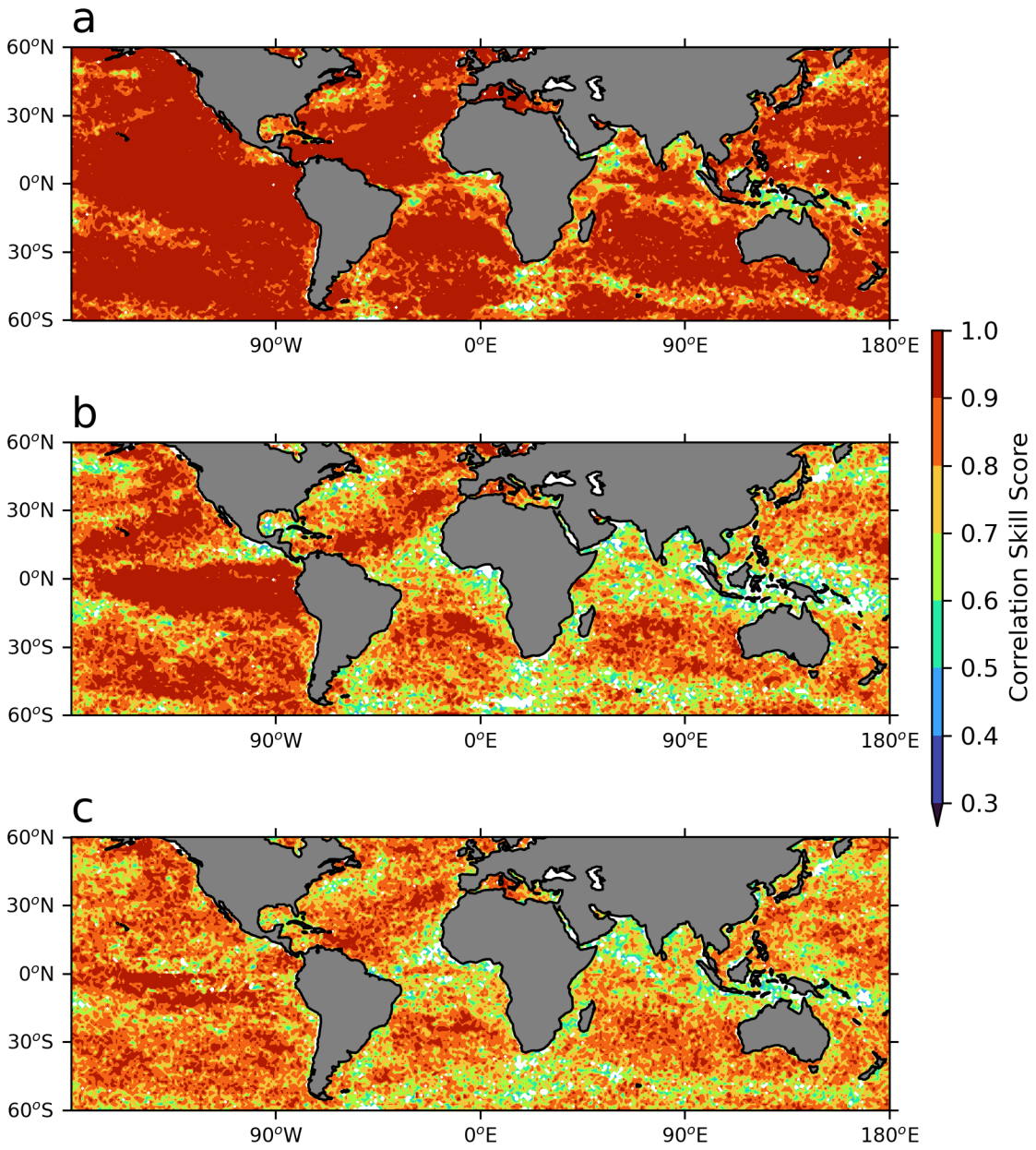

Fig. S2. GREP reanalysis representation of surface MHW interannual variability. Correlation skill scores of surface MHW indicators in ESA CCI satellite data and GREP reanalysis SST for Number of MHW days (a), Strongest intensity event (b) and Number of events (c). Regions where skill scores are insignificant are masked out.

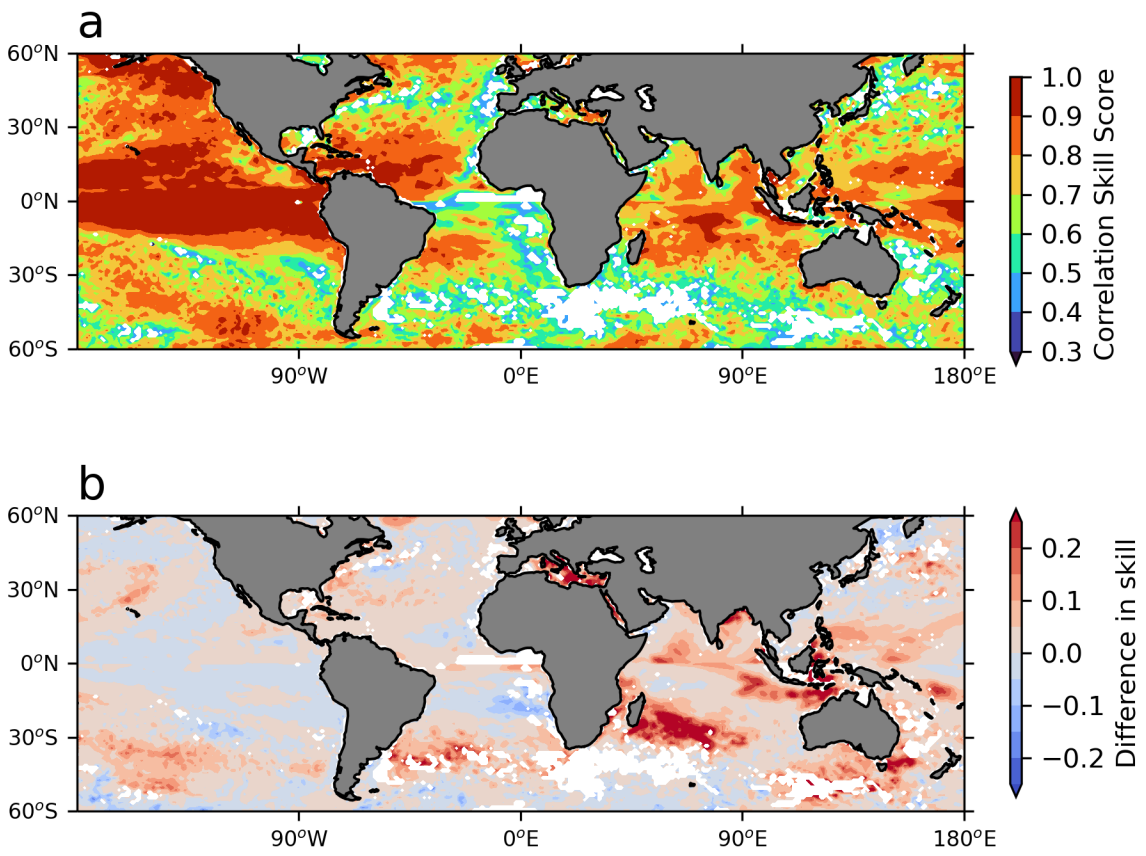

Fig. S3. Seasonal forecast skill of summer OHC 0-40 m anomalies. (a) Correlation of anomalies of seasonally averaged OHC 0-40 m in CMCC-SPS3.5 and GREP. (b) Increase in skill of anomalies of seasonally averaged OHC 0-40m when the trend is included. All scores correspond to the hemisphere-specific summer season and the 1993-2016 period. No statistically significant correlation differences are found in (b).

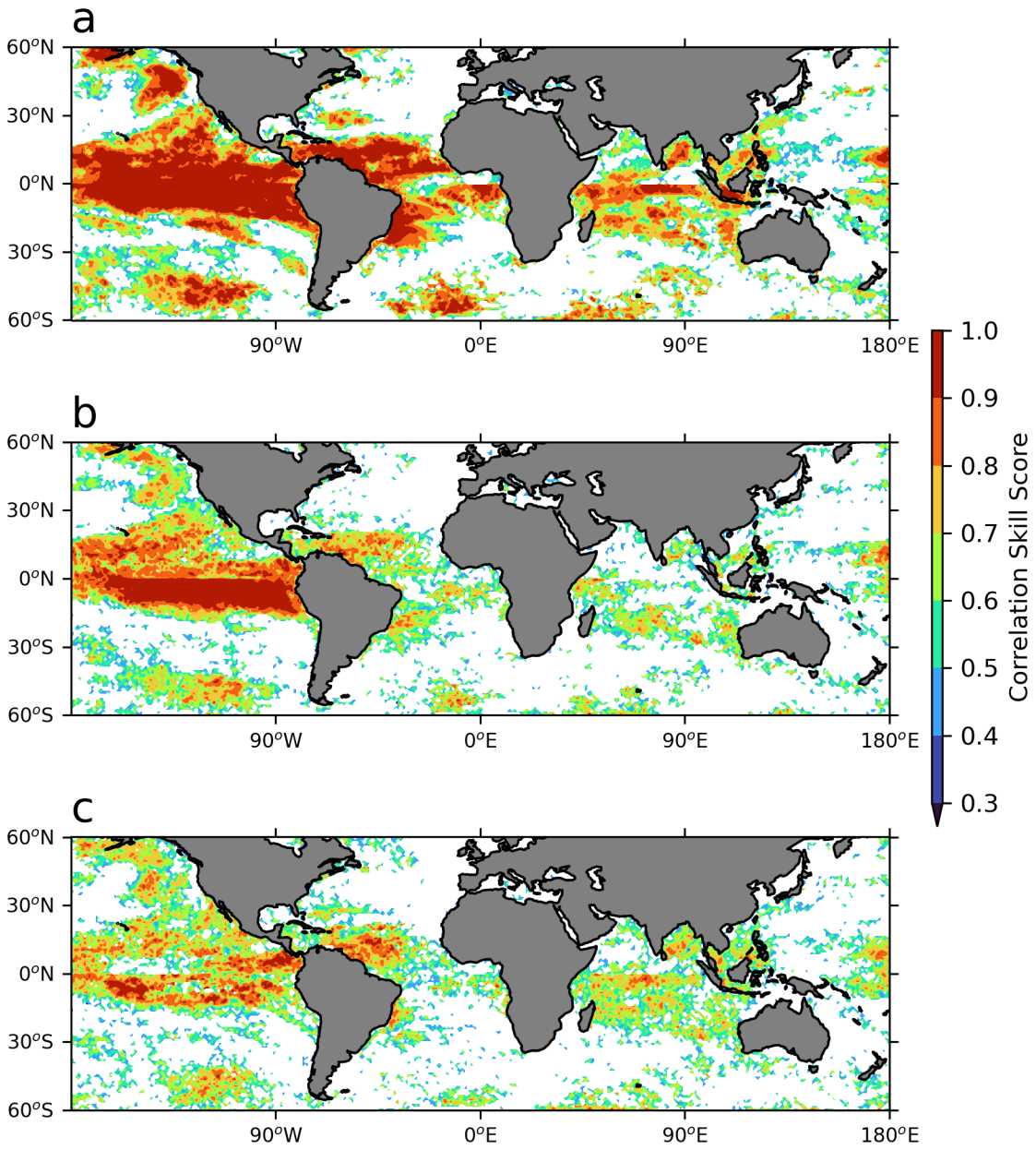

Fig. S4. Skill of surface MHW Indicators. Correlation skill score of surface MHW indicators for Number of MHW days (a), Strongest Intensity (b) and Number of events (c). All scores correspond to the hemisphere-specific summer season and the 1993-2016 period. Regions in which skill scores in both models are insignificant are masked out (white). Black stippling indicates statistically significant correlation.

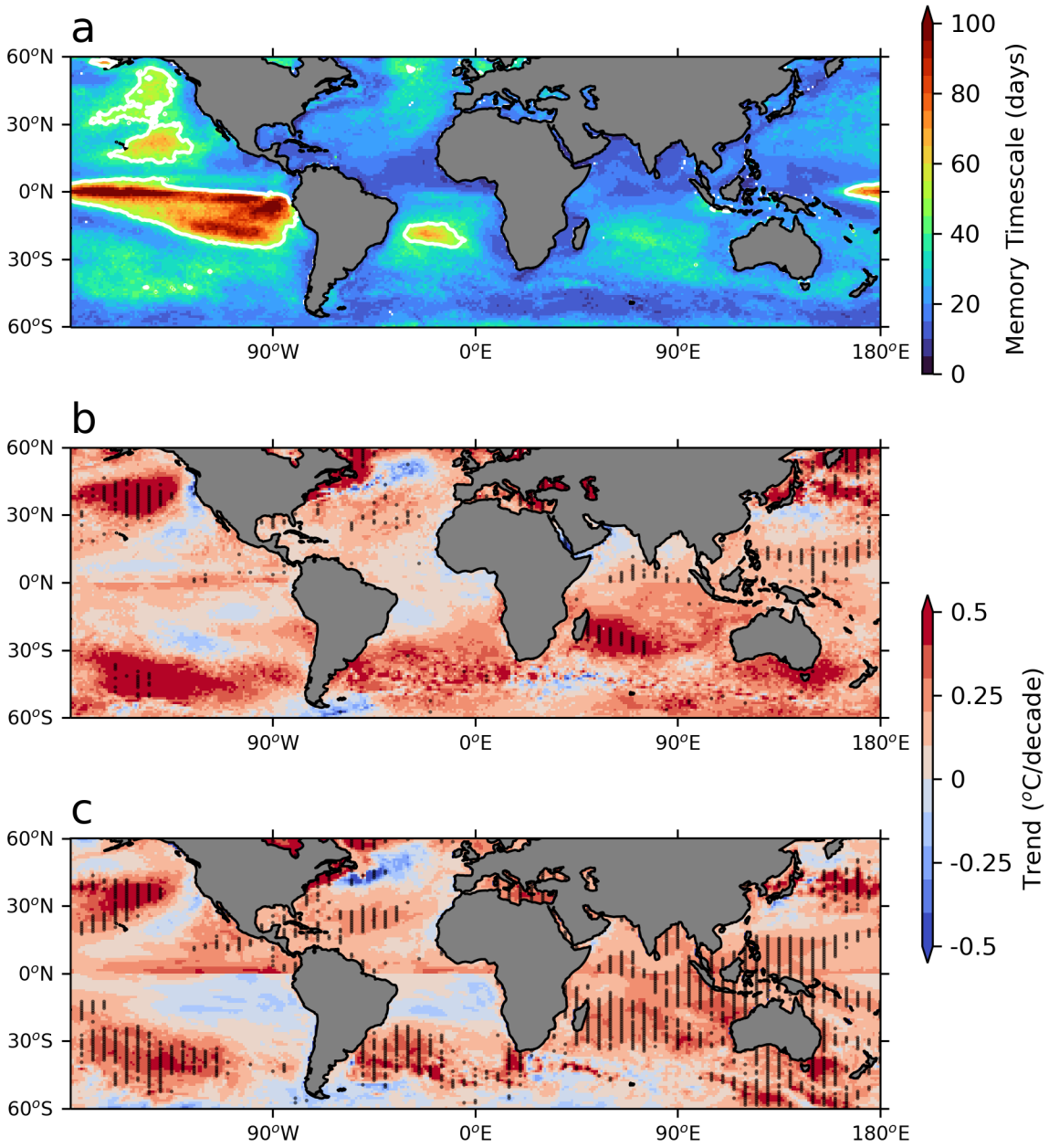

Fig. S5: Characteristic timescales and trends of SST. (a) Memory timescale (calculated from autocorrelation of SST; Methods). White contour corresponds to 45 days. Trends of summer average anomalies over 1993-2016 are shown for ESA CCI (b) and CMCC-SPS3.5 forecasts (c). Black stippling highlights statistically significant trends (using a Mann Kendall test and a p-value threshold of 0.05; Methods).

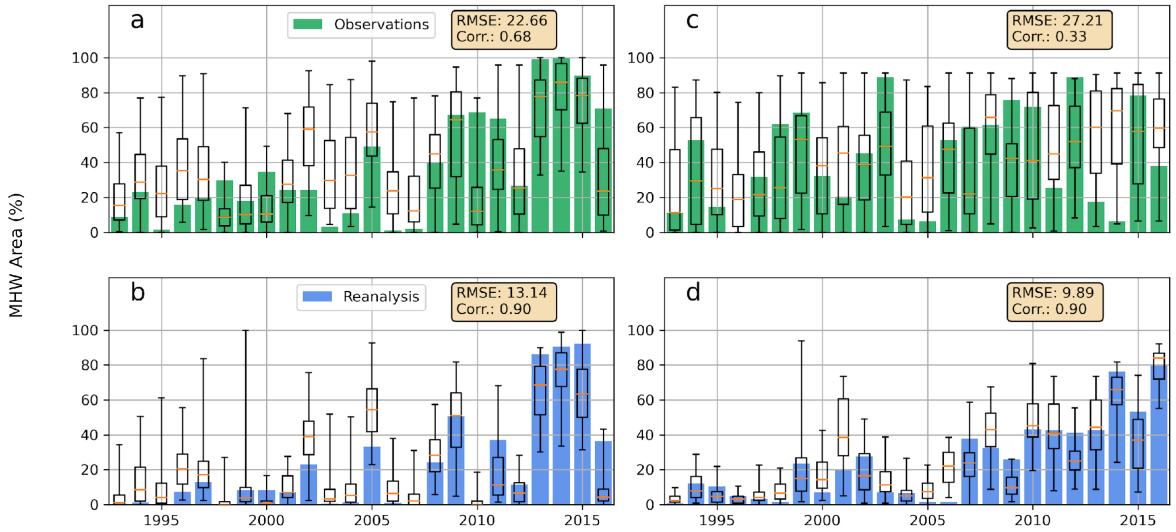

Fig. S6. Record of surface and subsurface MHW spatial extent in two regions of high MHW activity. The area in which MHW activity occurs over the summer season for (a) surface North Eastern Pacific (b) subsurface North-Eastern Pacific (c) surface Eastern Mediterranean Sea & (d) subsurface Eastern Mediterranean Sea. Box plots represent the median, interquartile range, and range of the 40-member forecast ensemble. Bar charts represent either the surface MHWs in the observations (green) or the subsurface MHWs in the reanalysis (blue). The MHW area corresponds to the total area which experiences some MHW activity during the summer, and is presented as a percentage of the total area. Root-mean square error (RMSE) and correlations between forecast ensemble medians and observation/reanalysis values are shown inset. See Figures 4 & 5 for the definition of the areas used.

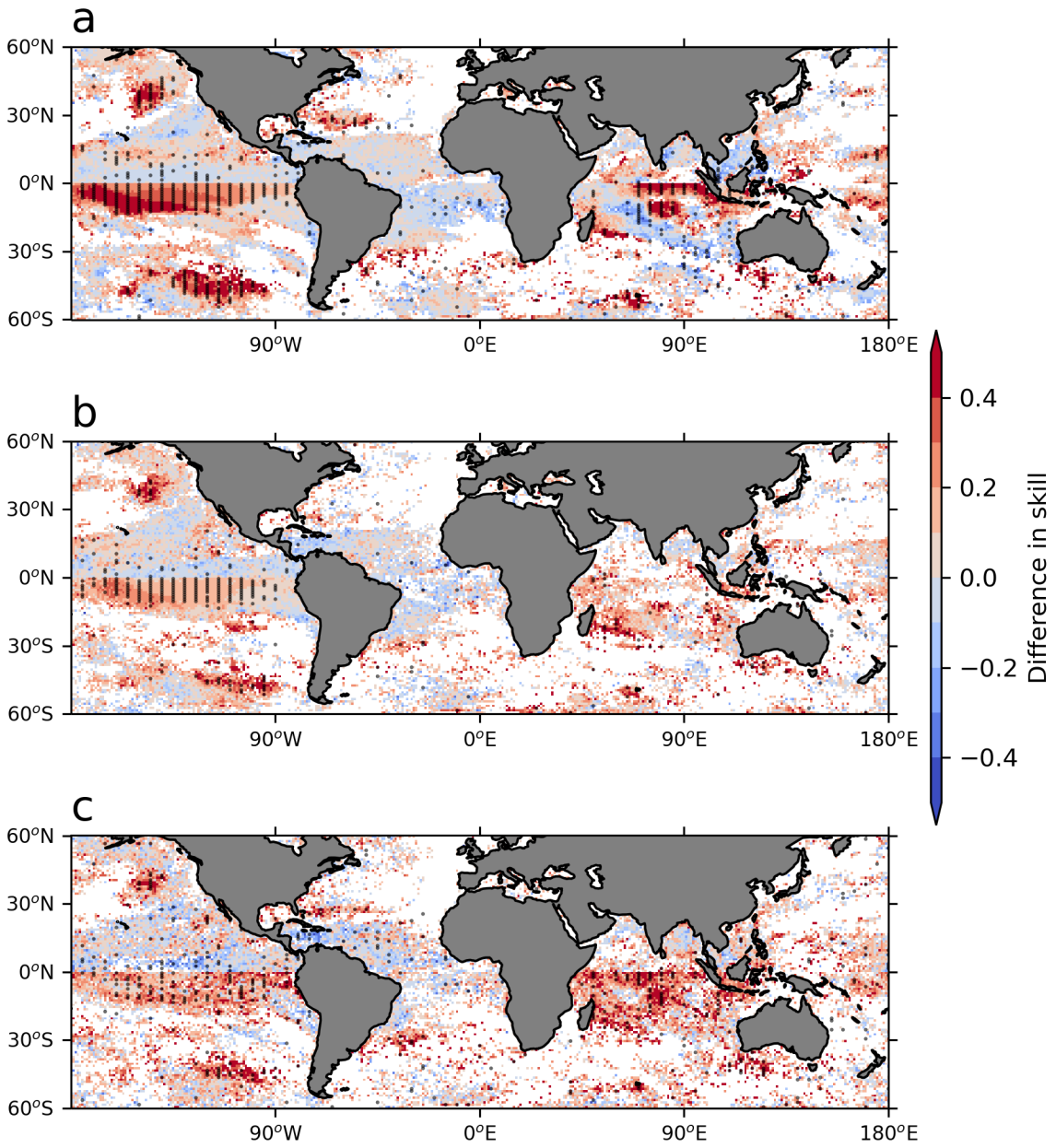

Fig S7. Contribution of linear trends to surface MHW forecast skill. Difference between skill scores of original forecast output (Figure S4 a, b & c) and detrended forecast output for Number of MHW days (a), Strongest Intensity (b) and Number of events (c). Positive values represent higher skill in the MHW reforecasts when the linear trend is included. All scores correspond to the hemisphere-specific summer season and the 1993-2016 period. Regions in which skill scores in both models are insignificant are masked out (white). Black stippling indicates statistically significant differences in correlation.

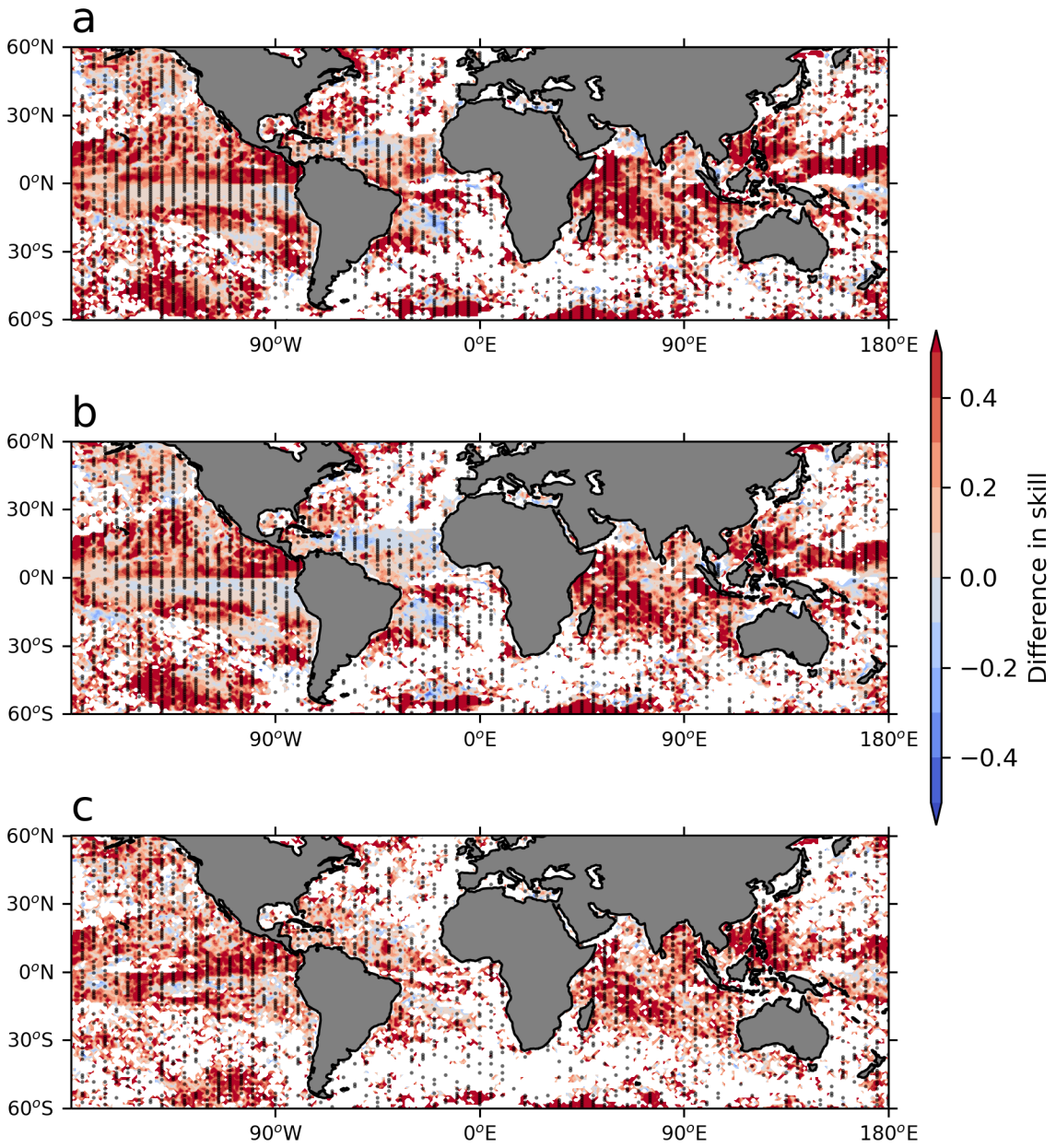

Fig. S8: Improvement of dynamical system subsurface MHW prediction over a persistence model. Similar to Figure 6, but no decay is applied to the persistence model. Difference between dynamical system skill scores (as seen in Figure 4 a, b & c) and persistence model skill scores in Number of MHW days (a), Strongest Intensity (b) and Number of events (c). Positive values represent higher skill in the dynamical system. All scores correspond to the hemisphere-specific summer season and the 1993-2016 period. Regions in which skill scores in both models are insignificant are masked out (white). Black stippling indicates statistically significant differences in correlation.