Trends, Variability and Predictive Skill of the Ocean Heat Content in North Atlantic: An Analysis with the EC-Earth3 Model

Teresa Carmo-Costa (reresa_maria@hotmail.com)
FCUL: Universidade de Lisboa Faculdade de Ciencias https://orcid.org/0000-0003-0255-2151

Roberto Bilbao
Barcelona Supercomputing Center: Centro Nacional de Supercomputacion

Pablo Ortega
Barcelona Supercomputing Center: Centro Nacional de Supercomputacion

Ana Teles-Machado
IPMA: Instituto Portugues do Mar e da Atmosfera

Emanuel Dutra
IPMA: Instituto Portugues do Mar e da Atmosfera

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Abstract

This study investigates trends, variability and predictive skill of the upper ocean heat content (OHC) in the North Atlantic basin. This is a region where strong decadal variability superimposes the externally forced trends, introducing important differences in the local warming rates, and leading in the case of the Central Subpolar North Atlantic to an overall long-term cooling. Our analysis aims to better understand these regional differences, by investigating how internal and forced variability contribute to local trends, exploring also their role on the local prediction skill. The analysis combines the study of three ocean reanalyses to document the uncertainties related to observations, with two sets of CMIP6 experiments performed with the global coupled climate model EC-Earth3: a historical ensemble to characterise the forced signals; and a retrospective decadal prediction system, to additionally characterise the contributions from internal climate variability. Our results show that internal variability is essential to understand the spatial pattern of North Atlantic OHC trends, contributing decisively to the local trends and providing high levels of predictive skill in the Eastern Subpolar North Atlantic and the Irminger and Iceland Seas, and to a lesser extent in the Labrador Sea. Skill and trends in other areas like the Subtropical North Atlantic, or the Gulf Stream Extension are mostly externally forced. Large observational and modeling uncertainties affect the trends and interannual variability in the Central Subpolar North Atlantic, the only region exhibiting a cooling during the study period, uncertainties that might explain the very poor local predictive skill.

Full Text

Due to technical limitations, full-text HTML conversion of this manuscript could not be completed. However, the latest manuscript can be downloaded and accessed as a PDF.

Figures

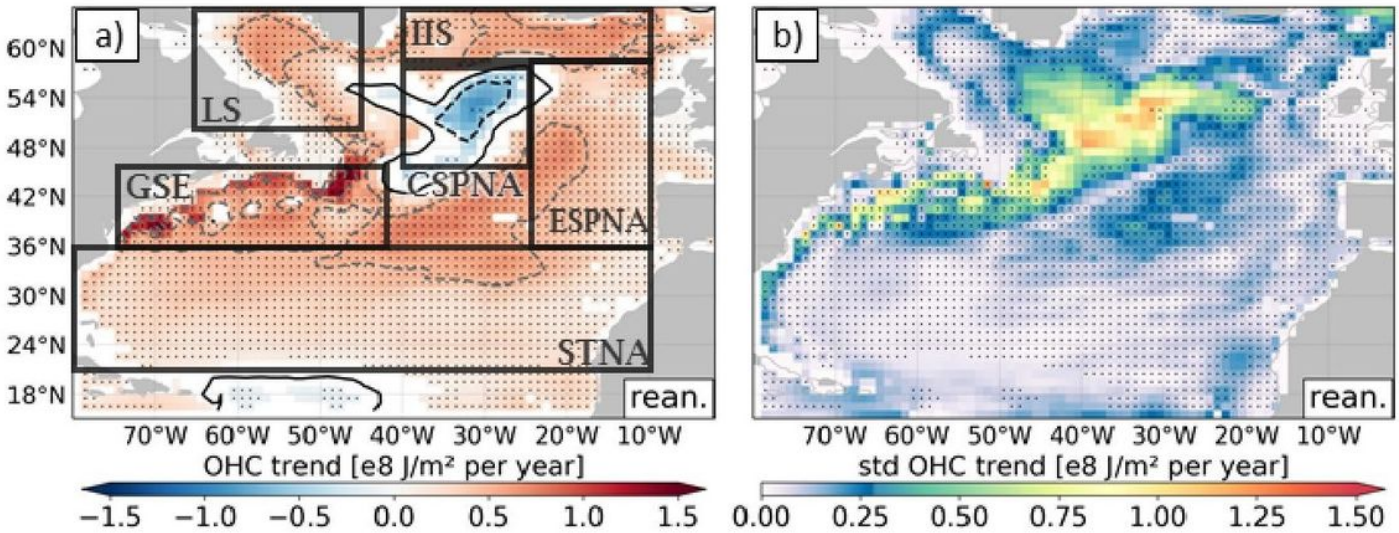

Figure 1

a) Map of the multi-reanalysis OHC700 mean trends over the period 1970-2014. Black boxes delimit the regions of interest specifically addressed in this study (See Table 2). Stippling is used to indicate the grid-points where the sign of the trend is the same in all the individual reanalysis. All trend values for which the trend is not significant are masked out in white. The full contour lines represent the zero trend and dashed lines show the subsequent trends in increments of 0.5 x 108J/m2 per year (grey/black lines indicate - positive/negative trends). b) Map of the standard deviation in the OHC700 trends across the reanalyses. The same stippling as in panel a) is included. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

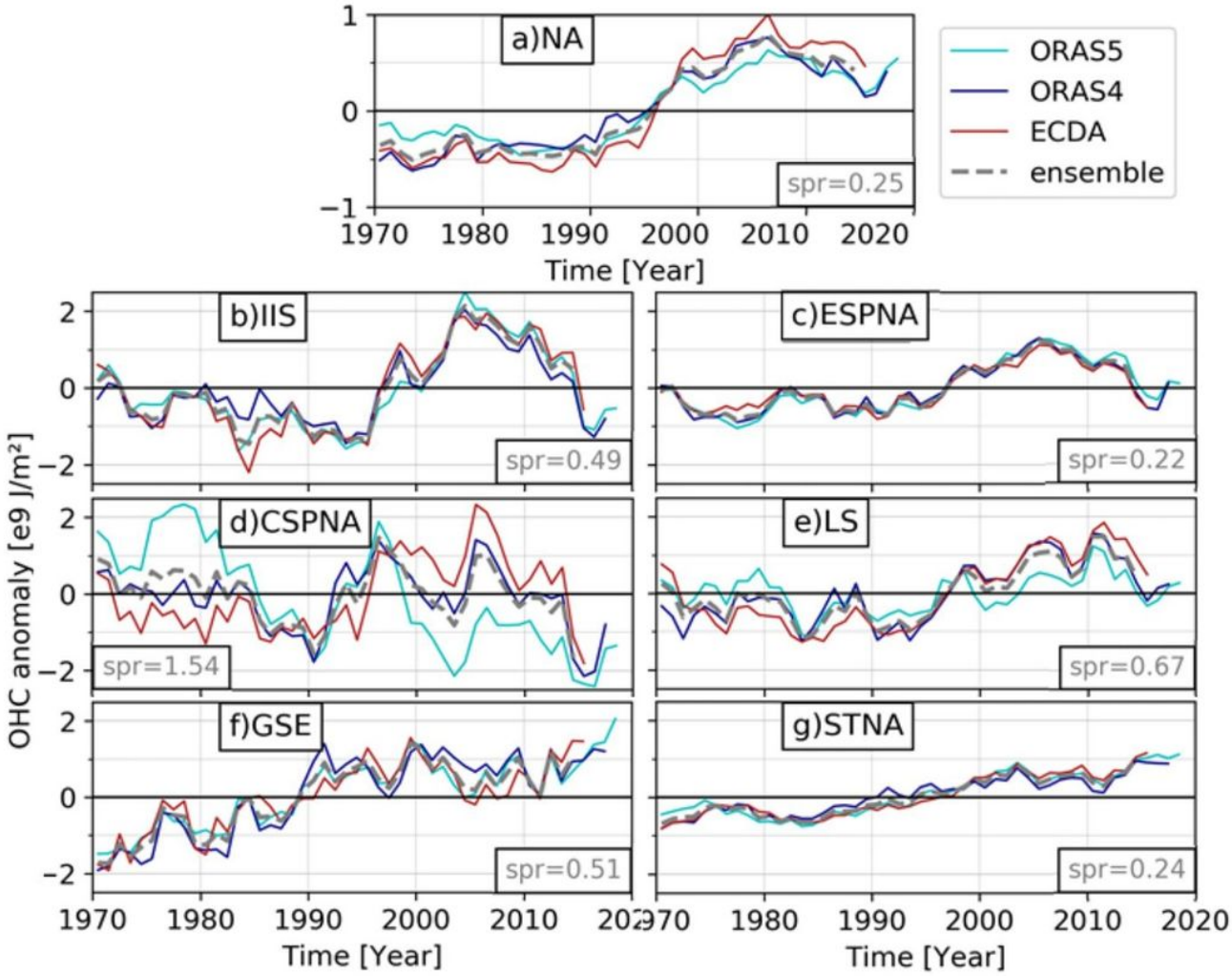

Figure 2

Time-series of the spatially averaged OHC700 across the NA and the selected sub-regions, computed from the reanalyses ORAS4, ORAS5 and ECDA, expressed as an anomaly per volume unit. The multi-reanalysis ensemble mean is also included (dashed grey line). Sub-regions are described in Figure 1 and Table 2. Note that y-scale is different for panel a). The degree of agreement in OHC700 variability across

the reanalyses is illustrated for each region by the temporal mean of the inter-reanalysis spread (defined by the range between the maximum and the minimum OHC700 values), indicated at the bottom corner of the panel.

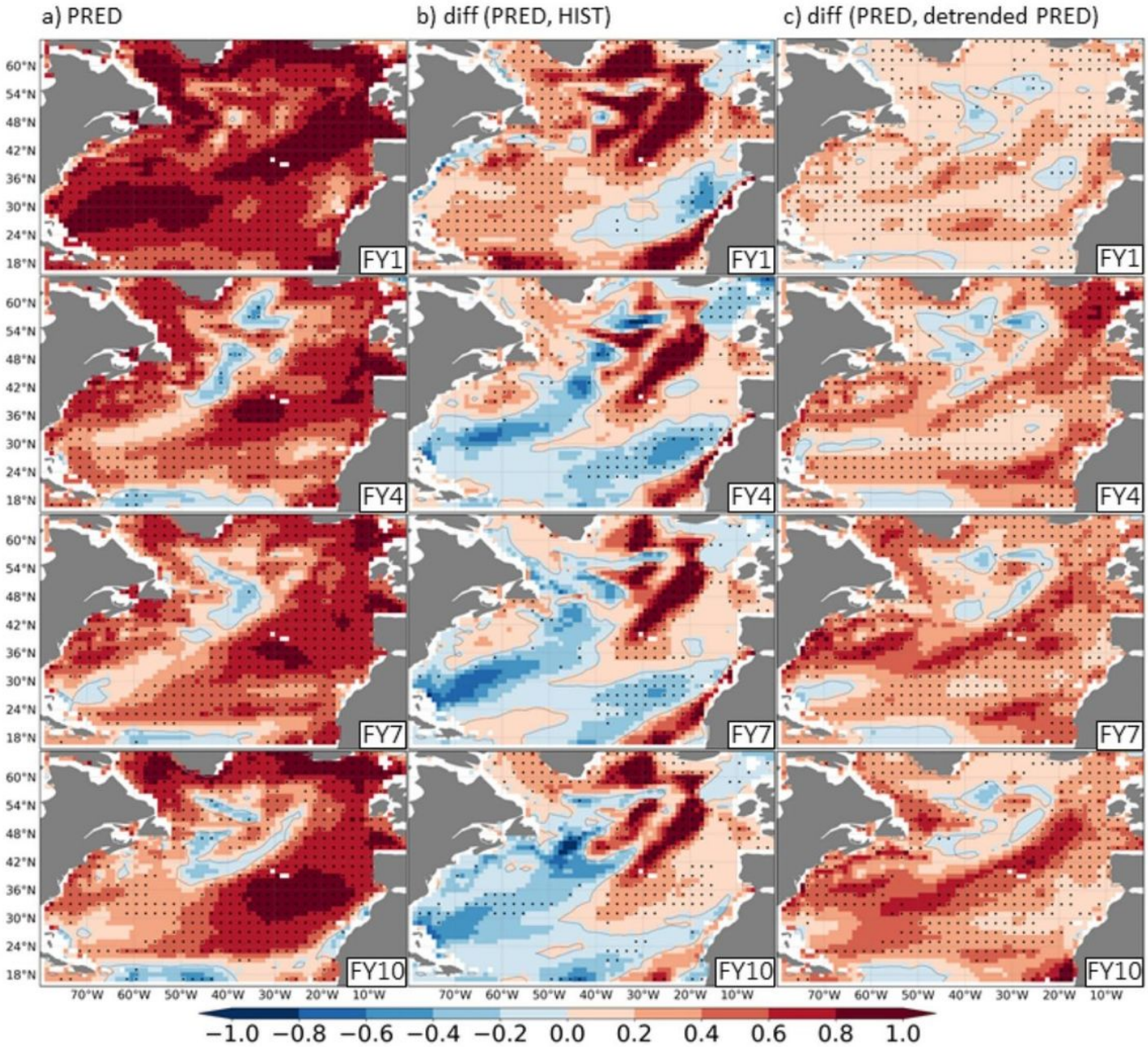

Figure 3

a) Anomaly Correlation Coefficient (ACC) maps of OHC700 in the initialised EC-Earth predictions for the forecast years 1, 4, 7 and 10. Stippling indicates where the correla tion is statistically significant at the 95% confidence level. Stippling is only applied in every 4th grid cell for the sake of visibility. b) Difference in the ACC values for the initialised and uninitialised predictions (PRED and HIST, respectively). c) Difference in the ACC val ues in PRED for the undetrended and the detrended OHC700 anomalies. In b-c) stippling highlights correlations that are significantly different at the 95% confidence level. All ACC values are evaluated against the multi-reanalysis ensemble mean for the period 1970-2014 Note: The

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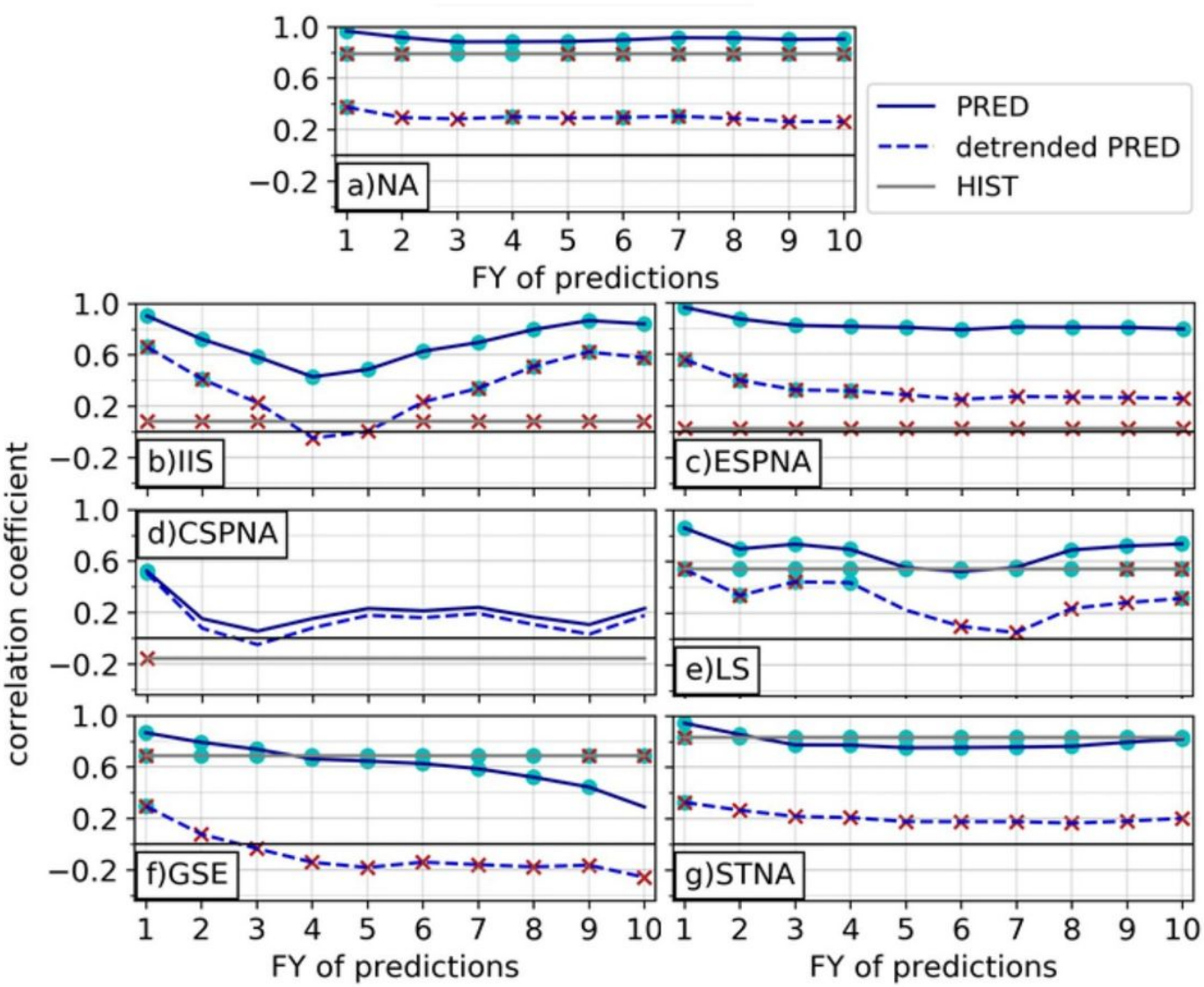

Figure 4

ACC skill assessment of the spatially averaged OHC700 in a) the North Atlantic, and b-g) all the selected individual regions. Skill values are shown for the PRED (blue lines) and HIST ensembles (grey lines) and are evaluated against the multi-reanalyses mean. In PRED, skill is also computed after detrending both the forecast anomalies and the reanalysed anomalies (detrended PRED; dashed blue lines). Cyan dots indicate ACC values that are significantly different from zero at the 95% confidence level. Red crosses indicate that the HIST or the detrended PRED ACC values are significantly different from the PRED ones.

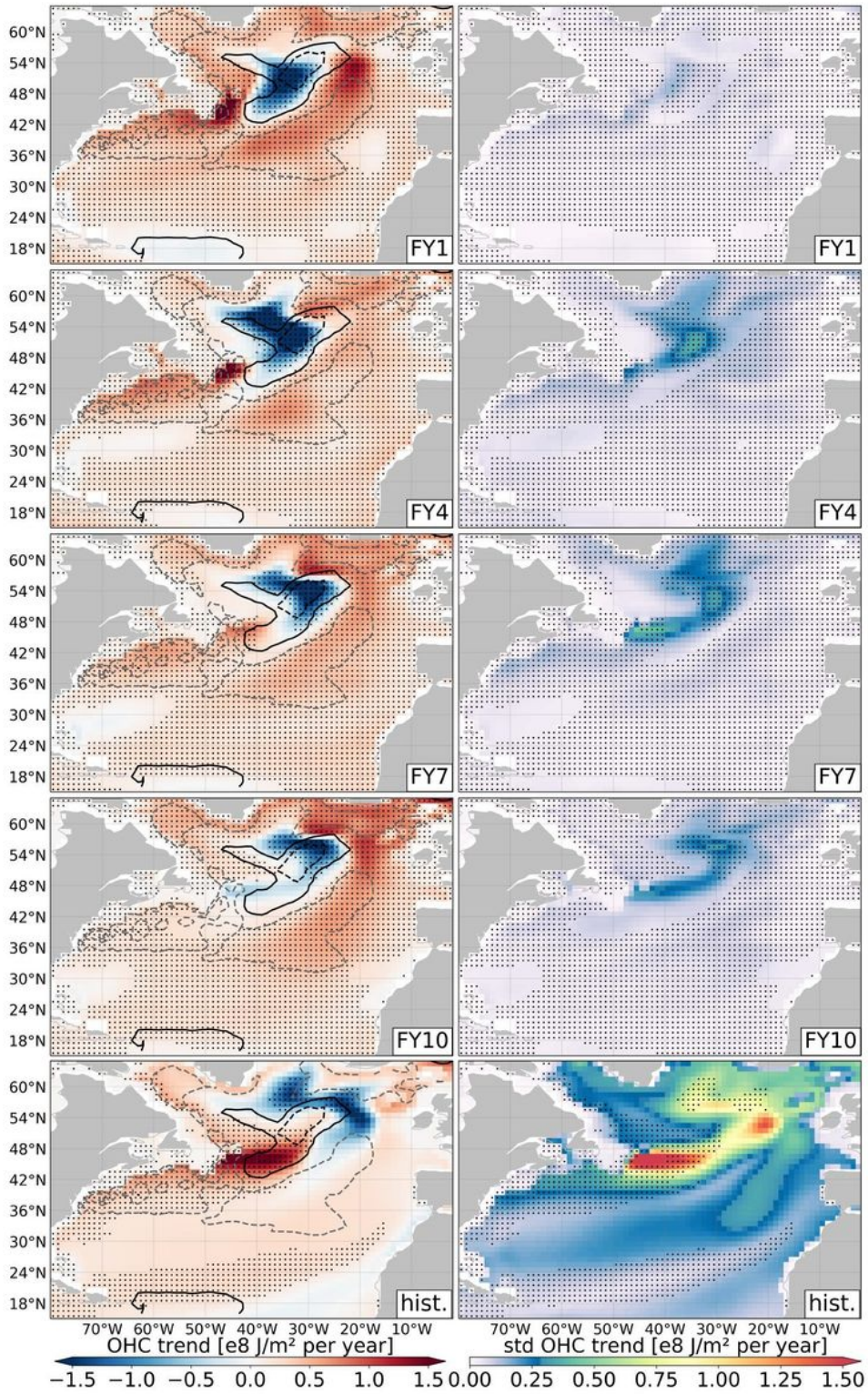

Figure 5

The same as in Figure 1 but for the EC-Earth3 hindcasts in forecast years 1, 4, 7, 10, and the historical simulations (final row). The ensemble mean OHC700 trend is shown on the left, and the standard deviation across the ensemble on the right. On both columns stippling is used to indicate the grid-points where the sign of the trend is the same in all individual members. Thick contour lines show the same multi-reanalysis mean trends as in Figure 1a. Note: The designations employed and the presentation of

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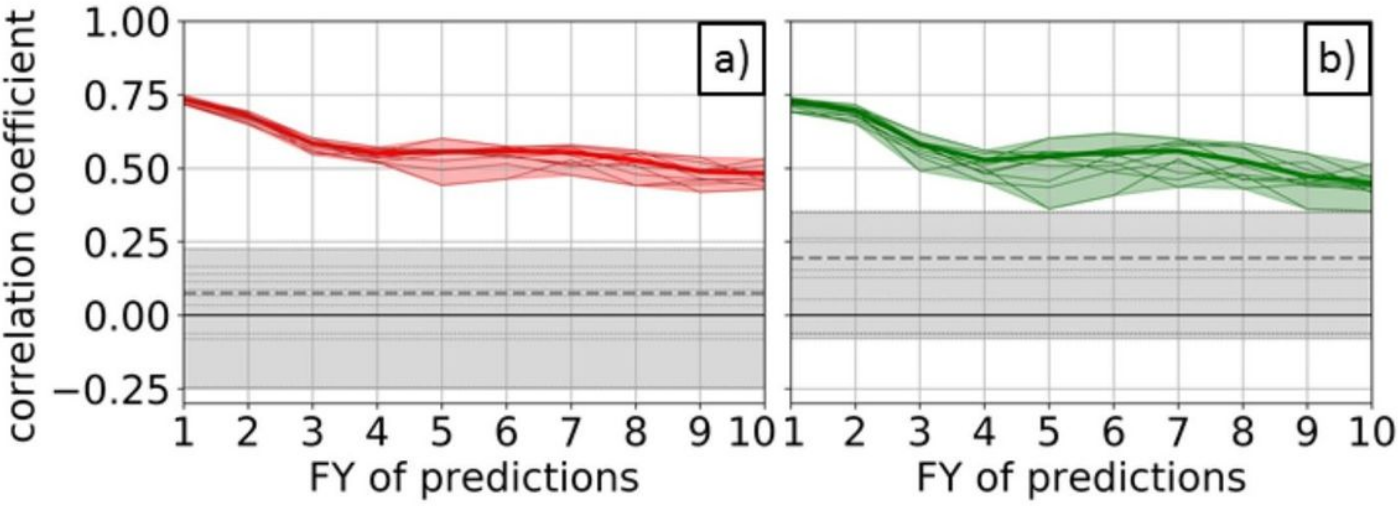

Figure 6

a) Area-weighted spatial correlations as a function of forecast time between the OHC700 trend patterns in the EC-Earth experiments (red for PRED, grey for HIST), and the trends in the multi-reanalysis mean. Thin lines represent the correlations for individual members in PRED and HIST, and the thick lines the corresponding values for their ensemble mean. The ensemble spread is indicated respectively by the red and grey shading. b) The same as in a), but with spatial correlations only calculated over the stippled grid points in Figure 1 (cells in which all reanalyses support a trend of the same sign).

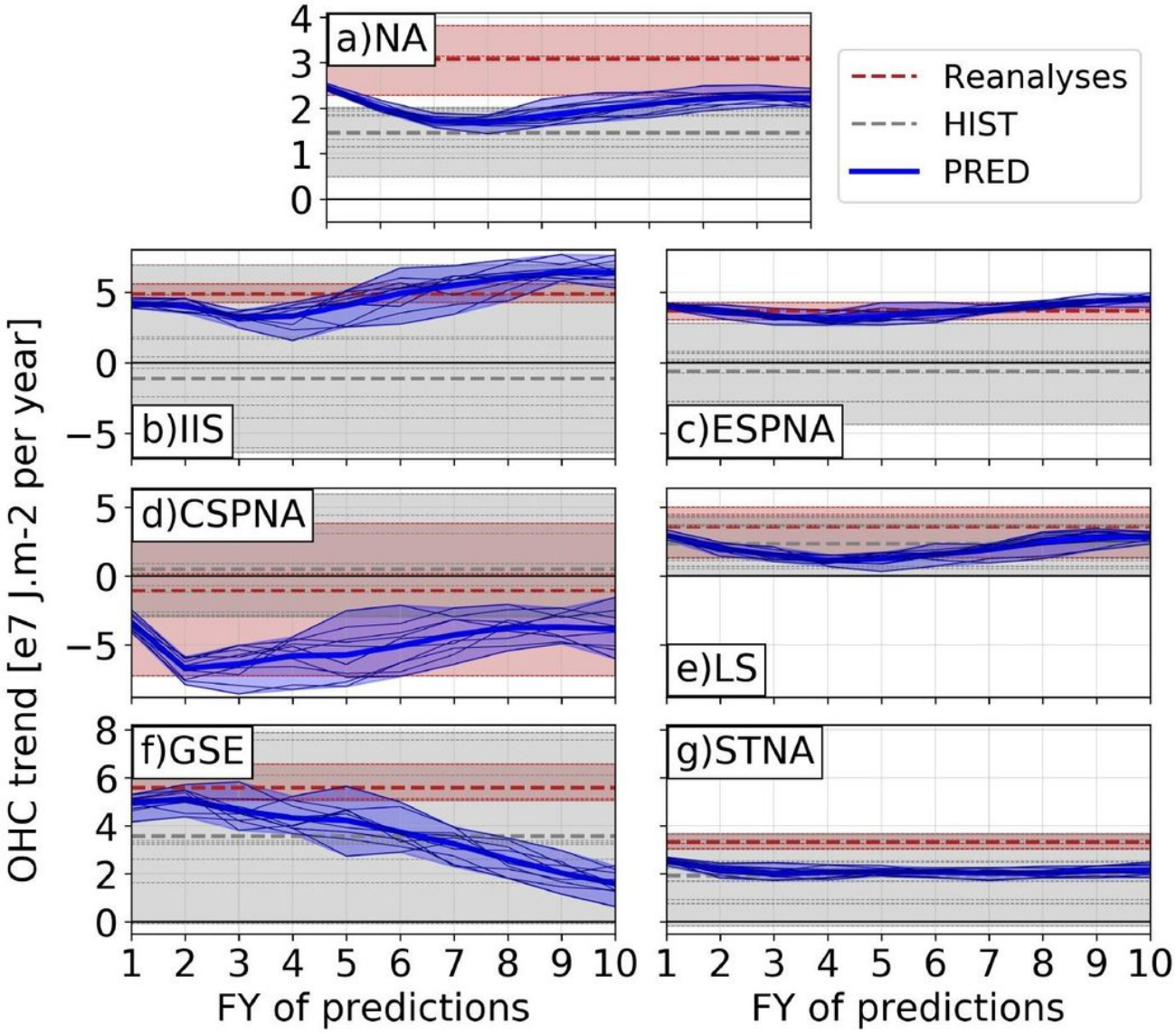

Figure 7

a) Spatially averaged North Atlantic OHC700 trends in the multi-reanalysis, PRED and HIST ensembles evaluated over the period 1970-2014, as a function of forecast time. The ensemble mean trends are represented by the dashed thick lines, and the trends for the individual members by the thin lines. Grid cells with non-significant trends are masked out before the regional averages are computed. Note that the y-axis is not the same for all panels, to improve the comparability of the different ensembles. b-g) The same as in panel a but for the selected NA regions: IIS, ESPNA, CSPNA, GSE and STNA.

Supplementary Files

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