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The global and regional structure of simulated historical ocean heat content change in CMIP6 models

Till Kuhlbrodt[1], Aurore Voldoire[2], Rachel Killick[3], and Matthew Palmer[3]
[1]University of Reading, NCAS, Meteorology, Reading, United Kingdom of Great Britain – England, Scotland, Wales (t.kuhlbrodt@reading.ac.uk)
[2]CNRM, Université de Toulouse, Météo France, CNRS, Toulouse, France
[3]Met Office Hadley Centre, Exeter, UK

Ocean heat content is arguably the most relevant metric for tracking the current global heating. Because of its enormous heat capacity, the global ocean stores about 89 percent of the excess heat in the Earth System. Time series of global ocean heat content (OHC) closely track Earth's energy imbalance, observed as the net radiative imbalance at the top of the atmosphere. Therefore, simulated OHC time series are a cornerstone for assessing the scientific performance of Earth System models (ESM) and global climate models. Here we present a detailed global and regional analysis of the OHC change in CMIP6 simulations of the historical climate (20th century up to 2014) performed with four state-of-the art ESMs and climate models: UKESM1, HadGEM3-GC3.1-LL, CNRM-ESM2-1 and CNRM-CM6-1. All four share the same ocean component, NEMO3.6 in the shaconemo eORCA1 configuration. Analysing only a small number of models allows us to extend our analysis from a global perspective, to also consider individual ocean basins.

For the global ocean, the two CNRM models reproduce the observed OHC change since the 1960s closely, especially in the top 700 m of the ocean. The two UK models (UKESM1 and HadGEM3-GC3.1-LL) do not simulate the observed global ocean warming in the 1970s and 1980s in the top 700 m, and they warm too fast after 1991. We analyse how this varied performance across the models relates to the simulated radiative forcing of the atmosphere and its components. All four models show a larger transient climate response (TCR) than the CMIP5 ensemble mean.

For the UK models, resolving the ocean warming in depth and time shows virtually zero historical warming at intermediate depths (700 m – 2000 m) whereas the global full-depth OHC change is reasonably simulated. After 1991, regional ocean heat uptake in the North Atlantic plays a substantial role in compensating small warming rates elsewhere.

A different picture emerges from the CNRM models. Globally the simulated OHC change is closer to observations, especially for CNRM-ESM2-1. Regionally the simulated OHC change is close to observations in the Pacific and Indian basins, while tending to be too small in the Atlantic, indicating a markedly different role for the Atlantic meridional overturning circulation (AMOC) and

for cross-equatorial heat transport between the CNRM models and the UK models. While the UK models simulate larger than observed historical warming below 2000 m in the Atlantic and South Pacific, the CNRM models take up heat at a larger than observed rate at intermediate depths in the South Atlantic and the South Pacific, with a much smaller role for the North Atlantic in global ocean heat uptake.