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Revisiting the relation between ocean heat storage and thermal expansion from a water mass perspective

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The excess anthropogenic ocean heat is causing thermal expansion, which has driven approximately 40% of the industrial-era global mean sea level rise. This relation between ocean heat uptake H and thermosteric sea level rise h_{θ} is mediated by the so-called expansion efficiency of heat ($EEH=h_{\theta}/H$, in m/YJ) which characterises the expansion of a water-mass under a unit increase of its enthalpy. The EEH of a water-mass depends on its temperature, salinity and pressure. At global scale the EEH has been characterized in both historical observations and climate simulations, but the the role of regional EEH and of individual water-mass layers in the formation of this global expansion efficiency remains undocumented. Here we propose a new approach where the EEH is decomposed in temperature coordinate into a temperature plus a pressure contribution to seawater thermal expansion. We show that the temperature contribution largely dominates the global signal. We also show that the global EEH can be interpreted as a weighted global average thermal expansion coefficient.

We make use of the global EEH decomposition in temperature coordinate to estimate the contribution of individual water-mass layers to global thermal expansion in both historical reference observational datasets and Climate Model Intercomparison Project (CMIP5-6) historical and scenario simulations. Results show a contrasting picture of water mass contributions to global thermal expansion and sea level rise. Whereas ocean warming is distributed between mode, intermediate and deep waters, a disproportionate share of global ocean expansion occurs within tropical waters and subtropical mode waters. Regionally, tropical Pacific waters and subtropical north Atlantic mode waters appear as key contributors to global thermal expansion. These results show that the regional distribution of ocean heat uptake is a key driver of thermal expansion and sea level rise not only at regional scale but also at global scale. We also show that projections of future sea level rise at global scale critically depend on the ability of climate models to simulate both the regional water mass properties and their heat uptake.