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Attribution of upper-ocean heat content changes using isothermal approach

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Changes of ocean heat content (OHC) play a critical role in understanding Earth's energy imbalance caused by human activities due to the large heat capacity of the ocean. A number of studies found anthropogenic influence on the long-term warming of the upper ocean, focusing on the upper 700 m which have better sampling of ocean data. However, causes of OHC changes at shallower ocean remain unclear owing to weaker magnitude of warming signal and large uncertainty associated with internal variabilities.

Separating contribution of surface air-sea heat flux (largely related to anthropogenic influence) from that of internal ocean dynamics is important for detecting external influences on the observed OHC changes, particularly at regional-scale changes. An isothermal approach has been suggested for this quantification. Here, we conduct an attribution analysis of upper-ocean heat content changes by applying an isothermal approach to observations and CMIP5 multi-models simulated under different forcing factors. The 14°C isotherm is applied following previous study, which represents the upper 220 m ocean and covers a large part of the global ocean.

Observations show the strongest and wide spread increase of heat content in the Atlantic Ocean. In the Pacific and Indian Oceans, warming and cooling trends appear together with increasing heat content in the eastern Pacific and southern Indian Oceans. Temperature contribution to the observed heat content trends is found to contribute to the overall uniform increase while depth contribution induces cooling patterns over the tropical Pacific and Indian Oceans. In model simulations with natural and anthropogenic forcings included, the heat content exhibits uniform increases with a stronger amplitude than the observations. Temperature and depth contributions are largely consistent with the observed.

In order to identify causes of the observed changes, observed and simulated changes in heat contents are compared using an optimal fingerprint technique. In this method, the observed changes are regressed onto the model response patterns and the regression coefficients are evaluated to determine which signals are present in the observed changes. Results show that anthropogenic signals are detected in the upper-ocean heat content globally and robustly in the contribution of isothermal temperature changes over all basins. In contrast, external signals are not detected in the contribution of isothermal depth changes, indicating that depth changes are associated with internal ocean dynamics. Exception occurs in the Atlantic Ocean where anthropogenic influence is detected also in the depth changes, and further investigation is needed to identify mechanisms. Our results provide the first evidence for human influence on the observed changes in upper-ocean heat content at 220 m depth with evaluating relative contributions of its thermodynamic and dynamic components.