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Southern Ocean water mass properties and circulation under CMIP6 climate forcing

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We examine the representation of Southern Ocean water mass properties, circulation and transformation in an ensemble of CMIP6 models, under historical climate forcing conditions and under a range of future climate scenarios. By using a dynamically defined water mass classification scheme based on physical characteristics (salinity minimum, potential vorticity minimum etc) rather than fixed water mass properties, we are able to compare water masses across a range of models, often with significant water mass property differences, as well as within single models where water mass properties change under climate forcing. We find that under strong climate forcing scenarios (ssp585) the heat content of SubAntarctic Mode Water (SAMW), Antarctic Intermediate Water (AAIW) and Circumpolar Deep Water (CDW) all increase consistently across models, while Antarctic Bottom Water (AABW) does not change significantly. Importantly this change is strongly modulated by using dynamic definitions. Both SAMW and AAIW lighten significantly in density, and using time varying definitions their volumes remain relatively constant, whereas using a time invariant definition both experience extremely significant increases in volume and heat content. We show that dynamically it is the ocean interior, CDW and AAIW, that dominate heat uptake under strong forcing. Similarly, dissolved inorganic carbon uptake occurs predominantly in the CDW. In contrast AABW volumes decrease significantly.

There is a consistent ‘fingerprint’ of temperature change in density space across all models under strong forcing scenarios, with CDW experiencing surface intensified warming as it shoals to the south, and SAMW/AAIW demonstrating cooling and freshening in their subducted layers and a uniform warming in the surface layers. We show that the upper cell of the residual overturning circulation (calculated with the new availability of eddy parametrisation terms in CMIP6) consistently increases across all models evaluated, by 10-50% (up to 10 Sv in some models), while the lower cell is dramatically decreased in strength, declining by up to 70% in some models. We provide evidence that surface warming may be modulated by increased eddy driven upwelling, as well as surface freshening driving the shutdown of AABW formation. Finally we compute a Walin water mass budget, balancing surface forcing, interior storage and meridional export and inferring interior mixing between water masses, and contrast all findings with similar analyses in CMIP5.