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Exploring the influence of atmospheric forcing on Sub-Antarctic Southern Ocean hydrography and air-sea CO_2 flux in coupled and ocean-only simulations

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Various intercomparison studies have demonstrated significant disagreements and biases in the Southern Ocean's (SO) representation in Earth System Models (ESMs). Examples include discrepancies in the strength and location of westerly wind forcing, water mass properties, or the seasonal air-sea CO_2 flux phase and strength. To better understand these discrepancies, we investigate the influence of atmospheric forcing and coupling on the SO hydrodynamics based on the ocean component of the UKESM1, consisting of NEMO (ocean physics), MEDUSA (marine biogeochemistry) and CICE (sea ice). We compare a fully coupled historical UKESM1 run and an ocean-only run initialised on 01/01/1980 from the coupled run but forced with the ERA-Interim atmospheric reanalysis between 1980-2014. The first years after initialising the ocean-only run shows a strong loss in upper ocean buoyancy (top 1000 m), reducing the overly strong stratification present in the coupled run compared to observations. In response the horizontal circulation changes, for example the Antarctic Circumpolar Current (ACC) extends deeper and is more confined meridionally in the ocean-only run while maintaining a similar strength. Furthermore, stratification and circulation changes allow for deeper winter mixed layers in the mode water formation regions north of the ACC in the ocean-only run, better matching the observations. Thus, the representation of mode water properties improves in the ocean-only run, as well as the overall water column structure. These highlighted differences between the two runs further affect the SO's export of water masses to the global ocean, and the local variability of biogeochemistry: for example, the seasonal cycle of air-sea CO_2 flux in mode water formation regions has the opposite phase in the coupled compared to ocean-only run. Our results highlight room for diverse improvements in the representation of SO dynamics in ESMs, ultimately improving global climate projections.