

Thesis Abstract

The Impacts of Climate Change on Southern Ocean Overturning Circulation and Subduction

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A multi-model comparison method was used to diagnose the projected changes of the rates of subduction, temperature and salinity properties, for the Southern Ocean upper limb water masses, Sub-Antarctic Mode Water (SAMW) and Antarctic Intermediate Water (AAIW). The corresponding changes in the surface heat and freshwater fluxes, and in the overturning circulation were also diagnosed. SAMW and AAIW ventilate the subtropical gyres, carrying heat, and dissolved gases into the interior. Changes in the subduction of these water masses can significantly alter the Southern Ocean uptake of anthropogenic CO₂. The results were partitioned into three analyses: a detailed assessment of the output from the CSIRO-Mk3.5 climate system model, a multi-model comparison of seven Intergovernmental Panel on Climate Change (IPCC) models simulating the late 20th century observed trends, and projected 21st century climate changes in the seven models.

Overall the seven models are able to produce observed spatial patterns during the 20th century, but with different magnitudes, spatial locations, and densities. For example, the models simulate the observed increases in surface warming and freshening in the Southern Ocean. There were significant correlations between the models and observations for changes in the SST, freshwater flux, and wind stress. In addition, the models can capture the observed cooling and freshening on density surfaces associated with SAMW and AAIW. The models' ability to represent the main features of the Southern Ocean climate implies that the models have skill to project changes in SAMW and AAIW.

In the A2 projection (where atmospheric is 860 ppm at 2100), the models show cooling and freshening on densities less than about 27.4 kg m⁻³, and this pattern has been observed over the late 20th century. There is a multi-model-mean (MMM) decrease in the export of fluid into the subtropical gyres, and an increase in the Southern Ocean heat content. In the 2090s, the westerly wind stress maximum strengthens and shifts polewards. Despite the increase in wind forcing, the MMM transport of the ACC shows little change (with a large spread across the models' results). This suggests that the strengthening of upper ocean stratification is compensating for the wind changes.

SAMW (defined by the low potential vorticity layer) and AAIW (defined by the salinity minimum layer) warm and freshen as they shift to lighter density classes. Warming and freshening at the ocean surface contribute more than 60% of the projected buoyancy gain at the SAMW and AAIW outcrops, whereas the increase in the Ekman flux of heat and freshwater contributes less than 30%. These changes in the buoyancy flux components, combined with shoaling of the winter mixed layer, reduce the volume of SAMW subducted into the ocean interior by a mean of 15 Sv ± 16 Sv. The changes in the subduction of AAIW vary greatly between the models, resulting in a small net MMM. The results of this thesis imply a future reduction in the Southern Ocean circulation, particularly driven by surface warming and freshening. The Southern Ocean absorbs 40% of the global anthropogenic CO₂, implying a likely decrease in the uptake rate.