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Pushing versus popping the cork: ocean heat and carbon uptake and outgassing responses to symmetric increasing versus decreasing atmospheric CO_2 concentrations

Karin Kvale (1), Katherine Turner (1,2), David Keller (1), Katrin Meissner (3,4)

(1) GEOMAR Helmholtz Center for Ocean Research, GEOMAR Helmholtz Center for Ocean Research, Kiel, Germany (kkvale@geomar.de), (2) University of Liverpool, UK, (3) Climate Change Research Centre, University of New South Wales, Sydney, Australia, (4) ARC Centre of Excellence for Climate System Science, Sydney, NSW, Australia

Surface atmospheric temperature has a weaker response to changing radiative forcing when atmospheric CO_2 concentration is reduced from a greenhouse to an icehouse climate than when it is increased from an icehouse to a greenhouse climate. This is because ocean circulation acts to slow ocean heat and carbon uptake with increasing atmospheric concentration, and acts to accelerate ocean heat and carbon release with decreasing atmospheric concentration. These statements are based on transient simulations using a coarse resolution model of intermediate complexity. We equilibrate the University of Victoria Earth System Climate Model, at 280 and 1260 ppm atmospheric CO_2, then force it with a 1% per year increase (the "ramp-up") and a 1% per year decrease (the "ramp-down") to compare the 500 year ocean circulation response. Both ramp-up and ramp-down simulations start from similar maximum global overturning strengths due the compensatory nature of buoyancy forcing in a salinity-conserving model, and similar northern hemisphere temperature gradients. However, the ramp-up ocean is initially dominated by deep convection in the North Atlantic whereas convection in the ramp-down ocean is more evenly distributed between the Southern Ocean, Atlantic, and Pacific basins. The collapse of Atlantic meridional overturning, and increased stratification in the ramp-up model slows ocean carbon and heat uptake. The forced reduction of atmospheric CO_2 in the ramp-down model stimulates vertical mixing in the Southern Ocean and North Atlantic basins, flushing deep carbon-rich water into shallower parts of these basins. This carbon degasses to the atmosphere, mitigating global mean temperatures and reducing the transient climate sensitivity. Our study has relevance for understanding earth system transitions between warm and cool climate states.