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Spin-up and adjustment of the Antarctic Circumpolar Current and global pycnocline

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The density structure of the Southern Ocean (and by association, the strength of the baroclinic Antarctic Circumpolar Current, ACC) is a key factor controlling the exchange of heat and carbon between the atmosphere and the deep ocean. Understanding how the baroclinic ACC responds to a change in forcing is important for understanding the response of the global ocean to anthropogenic forcing, and may help to explain changes in atmospheric CO2 concentration during glacial-interglacial transitions. Here, a theory is presented for the adjustment of the baroclinic ACC and global pycnocline to a sudden change in forcing. The adjustment timescale is controlled by the mesoscale eddy diffusivity across the ACC, the width of the ACC, and the surface area of the ocean basins to the north. Deep water formation in the North Atlantic is also likely to play an important role in the adjustment, although the relative importance of northern sinking and Southern Ocean eddies cannot be determined precisely, in particular due to limitations in the parameterization of northern sinking. While the theory also suggests that the adjustment timescale can be subtly modified by wind forcing and global diapycnal mixing, it is clear that the main processes that control the adjustment are not those that provide the energy to drive the ocean circulation, but rather the energy sinks. Results from calculations with a reduced-gravity model compare well with the theory. The multi-century adjustment timescale implies that long observational time series will be required to detect dynamic change in the ACC due to anthropogenic forcing. The role of Southern Ocean mesoscale eddy activity in determining both the equilibrium state of the ACC and the timescale over which it adjusts suggests that the response to anthropogenic forcing may be very different in coupled ocean-atmosphere climate models that parameterize and resolve mesoscale eddies.