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Time-scales and pathways of carbon sequestration in the Southern Ocean

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The Southern Ocean (SO) plays a critical role in the global carbon cycle, and will be increasingly important in the future. Subduction and formation of mode water transports nutrients and carbon from this High Nitrate Low Chlorophyll (HNLC) region to upwelling regions where they are reventilated supporting primary productivity. While it has been long recognized that this process sustains a significant part of the low-latitude primary productivity, it is less clear what these pathways mean for the global carbon cycle. How much of the carbon that leaves the SO is reventilated through these processes remains an open question. The fate of this carbon and the timescales associated with its reventilation, are critical to understanding current and future global carbon budgets.

Here we quantify the efficiency of the SO carbon uptake, and the relative importance of the physical and biological carbon pumps now and into the future. To this end, we use ocean biogeochemical simulations driven with observed and projected changes in climate. We focus on the upper ocean response in the present day, and at the end of the century (2100) and contrast these. These simulations allow us to separate the impacts of the biological and physical carbon pumps in the Southern Ocean on global nutrients, primary production and sea-air CO_2 flux. Importantly, the time-scale of carbon sequestration is much longer for the biological than for the physical carbon pump. Within 100 years, 70% of carbon sequestered by physical processes in the Southern Ocean is reventilated, at rates broadly consistent with the literature. Over the same time-scales only 45% of the carbon taken up by the biological pump has resurfaced. This can be explained by the sinking of particles to greater depths and its subsequent remineralization into waters with longer reventilation timescales.

The efficiency of the SO biological pump sets the concentration of macronutrients (nitrate and silicate) exported to the low-latitudes, where these in-turn control the amount of local primary productivity. If no macronutrients were utilized in the Southern Ocean, primary productivity north of 40°S would increase by 4.8 PgC yr-1 (14%). In other words, only 60% of Southern Ocean productivity would be compensated outside of the Southern Ocean on a 100 year timescale. This signal would occur in the whole Atlantic Ocean, but it would be limited to the equatorial upwelling region in the Pacific.

Given the diversity of projections of physics and productivity in the Southern Ocean, these considerations set the stage for discussing global implications and feedbacks by recent and projected future changes in the Southern Ocean carbon pumps due to global warming and strengthening of winds.