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Incorporating ecological and metabolic dynamics in modelling of ocean carbon cycle feedbacks

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The Earth's oceans act as the largest sink in the Earth system for anthropogenic CO_2 emissions through the action of the solubility and biological pumps, and so slow the accumulation of CO_2 in the atmosphere. Earth system models predict, though, that climate change will lead to a weakening in the rate of carbon uptake by the ocean as warm water holds less dissolved CO_2 and biological productivity declines. This weakening acts as a positive carbon cycle feedback on anthropogenic warming, thus increasing the risk of triggering climate tipping elements. However, most Earth system models do not incorporate the impact of ocean warming on the remineralisation of sinking organic matter through increased metabolic rates. Additionally, many models also rely on heavily simplified representations of plankton ecology featuring only a limited number of functional classes and traits – such as one-size phytoplankton and zooplankton classes in the common NPZD scheme – and so do not fully resolve the potential impact of climate change on plankton ecosystem structure. Here we use a recently-developed extension of the cGEnIE Earth system model of intermediate complexity (EcoGEnIE) featuring a trait-based scheme for plankton ecology (ECOGEM), and incorporate cGEnIE's temperature-dependent remineralisation (TR) scheme. This enables evaluation of the impact of both ecological dynamics and temperature-dependent remineralisation on the ocean carbon sink in response to climate change. We find that including TR strengthens the biological pump relative to default runs due to increased nutrient recycling, while including ECOGEM weakens the biological pump by allowing a shift to smaller plankton size classes. However, interactions with concurrent ocean acidification cause the opposite response for the ocean carbon sink: TR leads ultimately to a smaller sink relative to default runs whereas ECOGEM leads to a larger sink. Combining both TR and ECOGEM results in a net strengthening of the biological pump and a net reduction in ocean carbon sink relative to default. Enabling further plankton functional classes such as silicifiers and calcifiers will allow additional ecological dynamics to emerge in future versions of EcoGEnIE.