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Ocean sequestration of carbon dioxide and heat under global warming in a climate model with an eddy-rich ocean

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To robustly estimate how much carbon dioxide (CO_2) we may still emit while staying below a certain level of global warming, we need to know uncertainty in oceanic sequestration of CO_2 and heat. We here address uncertainty in oceanic CO_2 and heat sequestration that arises due to the representation of ocean mesoscale features. Such features are fundamental components of ocean circulation and mixing, though with spatial scales smaller than 100 km they are typically not resolved by climate models. We compare three configurations of the GFDL climate model that differ in the spatial resolution of the ocean, namely "eddy-rich" (0.10^{o} resolution) that simulates a rich field of mesoscale features such as mesoscale eddies and fronts, "eddy-present" (0.25^{o}) that simulates mesoscale features to a lesser extent, and "eddy-param" (1^{o} grid spacing) that does not resolve mesoscale features but represents effects of mesoscale eddies with parameterizations. The three models are run under preindustrial conditions and then exposed to an idealized increase of atmospheric CO_2 levels of one percent per year, until CO_2 doubling is reached.

We find that ocean mesoscale processes act to enhance the oceanic uptake of heat under global warming, while they act to reduce the uptake of CO_2 (eddy-rich relative to eddy-present). The greater heat sequestration is due to a greater reduction of the Atlantic Meridional Overturning Circulation, which redistributes heat from the Pacific to the Atlantic oceans, but also leads to an enhanced, albeit small, net global heat gain of several percent. Potential causes for the reduced sequestration of CO_2 (eddy-rich takes up 7% less relative to eddy-present) include reduced surface solubility of CO_2 due to the larger heating, or a different preindustrial state, e.g., of the buffer capacity. Eddy-param appears to not capture this effect; in contrast, it sequesters 13% more CO_2 than eddy-rich. While eddy-param largely captures the redistribution of heat between the Pacific and Atlantic oceans, it does not capture the enhanced net global heat gain. Despite the lower oceanic heat sequestration, eddy-param features a lower global atmospheric near surface warming of 0.4^{o}C at CO_2 doubling compared to eddy-rich and eddy-present, because heat is sequestered deeper in the ocean.

Our results suggest that opting either for resolving ocean mesoscale processes in climate models

or parameterizing their effects will affect the proportion of ocean heat versus carbon sequestration, with potential implications for the relationship of cumulative CO_2 emissions and global warming.