



Vector diagram analysis of ocean carbon pumps during the Last Glacial Maximum

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Using ocean carbon cycle model simulations of present-day and glacial climates, this study discusses the glacial responses of the ocean carbon pumps: organic matter, calcium carbonate, gas exchange, and freshwater pumps. The vector diagram presented here quantifies their individual impact on the glacial atmospheric $p\text{CO}_2$ reduction; the strengthening of the organic matter pump contributes to 40-ppm reduction of atmospheric $p\text{CO}_2$, most of which is cancelled by the weakening of the gas exchange pump. The response of the gas exchange pump is involved in various processes. Here, they are systematically revealed through analysis of additional sensitivity simulations. The analysis suggests that changes in the ocean deep circulation significantly affect the response of the gas exchange pump; the above-mentioned strong cancelation between the organic matter pump and the gas exchange pump is related to the glacial weakening of the Atlantic deep circulation. As in previous studies, the model used here fails to reproduce the observed magnitude of the glacial $p\text{CO}_2$ reduction. Reduced ventilation in the glacial Southern Ocean is a possible mechanism for explaining this difference since this has the potential to significantly modify the glacial response of the gas exchange pump but may not accurately be reproduced in the model. Although the gas exchange pump has often been implicitly incorporated into other processes, this study suggests that its response is a key to understanding glacial changes in atmospheric $p\text{CO}_2$. It is also demonstrated that the vector diagram is a useful tool for its investigation.