An analytical framework for the steady-state impact of carbonate compensation on atmospheric CO_2

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The deep-ocean carbonate ion concentration impacts the fraction of the marine calcium carbonate production that is buried in sediments. This gives rise to the carbonate compensation feedback, which is thought to restore the deep-ocean carbonate ion concentration on multi-millennial timescales. We formulate an analytical framework to investigate the impact of carbonate compensation under various changes in the carbon cycle relevant for anthropogenic change and glacial cycles. Using this framework, we show that carbonate compensation amplifies by 15-20% changes in atmospheric CO_2 resulting from a redistribution of carbon between the atmosphere and ocean (e.g., due to changes in temperature, salinity, or nutrient utilization). A counterintuitive result emerges when the impact of organic matter burial in the ocean is examined. The organic matter burial first leads to a slight decrease in atmospheric CO_2 and an increase in the deep-ocean carbonate ion concentration. Subsequently, enhanced calcium carbonate burial leads to outgassing of carbon from the ocean to the atmosphere, which is quantified by our framework. Results from simulations with a multi-box model including the minor acids and bases important for the ocean-atmosphere exchange of carbon are consistent with our analytical predictions. We discuss the potential role of carbonate compensation in glacial-interglacial cycles as an example of how our theoretical framework may be applied.