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Key Points:
- Time scale of the silicate weathering feedback is reassessed to be ~240 kyr
- Ten percent of added carbon dioxide persists in the atmosphere on ~240 kyr time scale
- Twenty-one percent of peak global temperature anomaly persists on ~240 kyr time scale

Supporting Information:
- Text S1, Figure S1 and S2, and Tables S1 and S2

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The time scale of the silicate weathering negative feedback on atmospheric CO_2

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Abstract The ultimate fate of CO_2 added to the ocean-atmosphere system is chemical reaction with silicate minerals and burial as marine carbonates. The time scale of this silicate weathering negative feedback on atmospheric pCO_2 will determine the duration of perturbations to the carbon cycle, be they geological release events or the current anthropogenic perturbation. However, there has been little previous work on quantifying the time scale of the silicate weathering feedback, with the primary estimate of 300–400 kyr being traceable to an early box model study by Sundquist (1991). Here we employ a representation of terrestrial rock weathering in conjunction with the "GENIE" (Grid ENabled Integrated Earth system) model to elucidate the different time scales of atmospheric CO_2 regulation while including the main climate feedbacks on CO_2 uptake by the ocean. In this coupled model, the main dependencies of weathering—runoff, temperature, and biological productivity—were driven from an energy-moisture balance atmosphere model and parameterized plant productivity. Long-term projections (1 Myr) were conducted for idealized scenarios of 1000 and 5000 PgC fossil fuel emissions and their sensitivity to different model parameters was tested. By fitting model output to a series of exponentials we determined the *e*-folding time scale for atmospheric CO_2 drawdown by silicate weathering to be ~240 kyr (range 170–380 kyr), significantly less than existing quantifications. Although the time scales for reequilibration of global surface temperature and surface ocean pH are similar to that for CO_2, a much greater proportion of the peak temperature anomaly persists on this longest time scale; ~21% compared to ~10% for CO_2.

1. Introduction

The legacy of human perturbation of the global carbon cycle will be a long one [*Archer*, 2005; *Archer et al.*, 2009]. The burning of fossil fuels, deforestation, and to a lesser extent cement production, creates an excess of CO_2 in the atmosphere (and associated climatic changes) that will persist until it is sequestered either by natural and/or anthropogenic means. Leaving aside potential deliberate anthropogenic intervention in the form of geoengineering [*Royal Society*, 2009], we focus here on improving understanding of the long-term natural carbon sinks—primarily the order $10^3 - 10^5$ year geologic processes.

On short time scales ($\sim 10^0 - 10^1$ years), excess CO_2 is absorbed from the atmosphere by the terrestrial biosphere through the "CO_2 fertilization" effect, as well as forest regrowth. The input of carbon is partly transferred to the soil where it is broken down and returned back to the atmosphere as CO_2 (or CH_4) on a $\sim 10^1 - 10^2$ year time scale. At the same time, the ocean removes excess atmospheric CO_2, initially by CO_2 dissolving in and reacting with surface waters. Dissolved CO_2 forms carbonic acid, which quickly dissociates into bicarbonate and carbonate ions, allowing more CO_2 to enter the ocean from the atmosphere. This buffering allows approximately a factor of 10 more carbon to be absorbed by the ocean than would be the case were it to remain undifferentiated like oxygen [*Revelle and Suess*, 1957]. Both the land and ocean carbon sinks are thought to currently absorb ~30% each of the excess atmospheric CO_2, with the land sink being more variable on a multiyear time scale [*Le Quéré et al.*, 2009]. However, as more CO_2 enters the atmosphere, the immediate terrestrial and oceanic sinks become less able to absorb excess atmospheric CO_2 [*Canadell et al.*, 2007; *Le Quéré et al.*, 2007]. Indeed the airborne fraction of CO_2 (remaining over emitted, per annum) may have increased from 40% to 45% in recent decades [*Le Quéré et al.*, 2009].

The addition of CO_2 to seawater causes ocean acidification through the release of protons during the dissociation of carbonic acid into bicarbonate and the depletion of carbonate ions. Once the ocean is mixed down to depth, the reduced carbonate ion concentration causes the Carbonate Compensation Depth (CCD;