The geoengineering potential of artificially enhanced silicate weathering of olivine

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Abstract

Geoengineering might manipulate Earth’s climate in order to counteract global warming from anthropogenic greenhouse gas emissions. We investigate in detail the potential of a specific geoengineering technique: carbon sequestration by artificially enhanced silicate weathering via the dissolution of olivine. This approach would not only operate against rising temperatures but would also counteract ocean acidification, because it influences the global climate via the carbon cycle. We here show the consequences of this technique for the chemistry of the surface ocean at rates necessary for geoengineering. We calculate that olivine dissolution has the potential to sequester up to 1 Pg C yr⁻¹ directly, if olivine is distributed as fine powder over land areas of the humid tropics. The enhanced silicate weathering flux would sequester annually up to 4.3 and 0.6 Pg of carbon, respectively, in case the resulting pH is the threshold (Table 1). That implies a potential of enhanced silicate weathering to reduce atmospheric CO₂ in the future.

Table 1: Upper estimate of CO₂ sequestration by olivine dissolution on land, if the pH of major rivers in the humid tropics is given. Assumptions: typical riverine partial pressure of CO₂, alkalinity threshold is 8.0, 8.2 or 9.0. The enhanced silicate weathering flux would sequester approximately as much of CO₂ (or about 27% as much in C) as olivine was dissolved. TA is the total alkalinity.

<table>
<thead>
<tr>
<th>Units</th>
<th>Amazon</th>
<th>Congo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment area (10¹² m²)</td>
<td>5.83</td>
<td>3.6</td>
</tr>
<tr>
<td>Runoff (10¹² m³ yr⁻¹)</td>
<td>6.3</td>
<td>1.3</td>
</tr>
<tr>
<td>TA (mmol m⁻³)</td>
<td>460</td>
<td>290</td>
</tr>
<tr>
<td>pCO₂ (μatm) *</td>
<td>3430 (385 – 13000)</td>
<td>3200 (385 – 35600)</td>
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Background

Most geoengineering concepts focus either on the restriction of the proposed temperature rise through an artificial enhancement of the planetary albedo (Solar Radiation Management (SRM)) or on removing CO₂ from the atmosphere by various Carbon Dioxide Removal (CDR) techniques. The SRM techniques leave the carbon cycle untouched, and thus do not address the problem of ocean acidification. This would for some of the IPCC emission scenarios lead to a drop in the surface water pH of up to 0.4 and to a drop in the aragonite saturation state by a factor of two in the year 2100. It would thus bring various marine calcifying species, which depend in the build-up of their hard-shells or skeletons on the over-saturation of CaCO₃, into unfavorable environmental conditions, to which their degree of adaptation is yet unknown. In the worst case their carbonate parts might dissolve.

Our analysis expands results from previous studies on the impact of natural weathering in the future. Olivine (Mg₂SiO₄) is a well studied mineral with known dissolution kinetics and has been suggested to be useful for CDR geoengineering (Figure 1). This study focuses on the humid tropical regions, because of the high temperature, wet conditions and low soil pH. These conditions allow for relatively rapid dissolution of olivine.

Findings & Conclusion

The Amazon and Congo river basins have an artificial silicate weathering potential to sequester annually up to 4.3 and 0.6 Pg of carbon, respectively, in case the resulting pH is the threshold (Table 1). That implies a potential of enhanced silicate weathering to reduce atmospheric CO₂ in the future. To achieve that, fine grained olivine has to be distributed over land areas of the humid tropics. The carbon sequestration potential in soils is limited by the saturation concentration of silicic acid. In our calculations for the Amazon and Congo river catchments, a maximum annual dissolution of 1.8 and 0.4 Pg of olivine seems possible, corresponding to the sequestration of 0.5 and 0.1 Pg C yr⁻¹. Based on these results, the carbon removal rate might be higher, in case additional regions or alternative, artificial weathering techniques are considered (House et al., 2006).

An artificial weathering rate of 1 Pg C yr⁻¹ reduces pCO₂ by less than 30 μatm (equivalent to a cooling of 0.2 K) until the year 2100 (Fig. 3). An artificial weathering rate of sequestering 5 Pg C yr⁻¹ would reduce pCO₂ by 80 to 150 μatm (cooling of 0.6-1.1 K) and would increase pH by about 0.1 until the year 2100. Sequestration of 10 Pg C yr⁻¹ potentially reduces pCO₂ by 160 to 300 μatm (cooling of 1.2 to 2.2 K). The mean surface ocean pH would rise by about 0.2 in that scenario. However, the amount of olivine necessary for these applications is huge, it lies in the range of present day global coal production.

Nevertheless, compared to other CDR techniques silicate dissolution is very effective, rated as relatively safe and moderately expensive. Ecosystem assessments for the expected impacts of the enhanced weathering are needed here. We finally calculate with a carbon cycle model the consequences of sequestration rates of 1 to 5 Pg C yr⁻¹.