Geoengineering debate

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Introduction

Geoengineering is the deliberate, large-scale modification of the Earth's climate to limit or reverse global warming.

Let us remember that the temperature of any object results from the balance between the energy it receives from the environment and the energy emitted by the object itself to the outside. In the case of the Earth, the main input of energy is what it receives from the Sun. A part of this energy is not absorbed by the Earth but is reflected back into space. The proportion of solar radiation reflected is the **albedo**. A light-colored surface, such as snow or a desert, has a higher albedo than a dark surface, such as a forest or the open ocean.

On the other hand, the Earth, like any other object in the universe, emits electromagnetic energy into space following the Stephan-Boltzmann law. Energy is emitted at a certain wavelength that depends on the temperature of the object. At Earth's temperature, the energy emitted is infrared and part of it is absorbed by gases found in the atmosphere that are known as **greenhouse gases** (or GHGs). CO_2 is the most important GHG, and its concentration has been increasing at a good pace for more than a century.

Geoengineering methods are divided into two large groups. The first aims to reduce the amount of energy received from the Sun by increasing the Earth's albedo. The reasoning is very simple: if the Earth receives less energy from the Sun, it will cool down.

The second group of methods seeks to reduce the concentration of CO_2 in the atmosphere using natural or artificial processes. The reasoning is again very simple: if there is less CO_2 in the atmosphere, the Earth will emit more energy into space and will therefore cool down.

It is well known that the fight against climate change would be won if anthropogenic CO_2 emissions were significantly reduced. But experience shows that this has not happened so far despite the efforts of multiple people, countries, and institutions. The truth is that the concentration of CO_2 continues to increase inexorably.

It is at this point where geoengineering appears. Since we are not able to stop anthropogenic CO_2 emissions, geoengineering will have to be used, some say. The problem is that no geoengineering method is perfect. Some are very expensive; others are technologically impractical, at least today; others could have dangerous side effects.

Global warming is a colossal challenge for humanity. We believe that it is important for students of disciplines such as Biology or Environmental Sciences to know geoengineering and its main methodological proposals. However, we do not want to limit ourselves to explaining this content in master classes, but rather we prefer that the students themselves discover the pros and cons of their possible uses. Using some geoengineering methods can be dangerous, but doing nothing can be even worse. Other geoengineering methods may be safe, but their effectiveness may be minimal. Science does not yet have the answers to these questions, which is why we discuss these topics in the form of a **debate** in our classrooms.

Development of the debate

We have been carrying out the geoengineering debate in the Ecology subject of the Environmental Sciences degree at the UAB since 2014. Below we present the way in which we approach the debate in case it can be useful to teachers of other subjects or other universities. Obviously, its implementation depends greatly on the circumstances of each subject, the characteristics of the group of students and the preferences of the teaching staff. What follows is nothing more than a suggestion resulting from our experience.

Our subject is third year and there are usually between 60 and 80 students. We give an introduction of about 30 minutes to this debate with the entire group; this classroom presentation was changed to home video during the COVID epidemic and now to better quality video. After a few weeks we do the debate itself in a two-hour session with the class divided into two halves.

We do not raise the debate about geoengineering as a whole, but only with some of the methods. As there are many, we select four of them, two for controlling solar radiation (*e.g.*, injection of aerosols in the stratosphere and artificial generation of clouds in the ocean) and two for reducing atmospheric CO_2 (*e.g.*, artificial extraction of atmospheric CO_2 and addition of nutrients to the ocean or reforestation).

We divided the class into 16 subgroups of 3-4 students and each of them was assigned a geoengineering method. Since there are 16 subgroups and 4 methods, each method is addressed by four subgroups. Since the session is repeated for both halves of the class, in each session there are two subgroups for each geoengineering method. We ask all groups to prepare a short PowerPoint with the basics of the method and its pros and cons. We ask one of the subgroups of each method to argue in favour of the method and the other subgroup to argue against it. The two-hour session is divided into about 20 minutes for each of the four chosen methods plus a general debate of another 20 minutes.

The evaluation is carried out based on the quality of the PowerPoint prepared and its presentation and debate in the classroom (50%) and with a question in the subject exam (50%).

Bibliography

The first effort to list, describe, characterize, and compare most geoengineering methods was made by *The Royal Society of London for Improving Natural Knowledge* (The Royal Society, 2009). This report qualitatively characterizes each geoengineering method along four axes: **effectiveness** (does it reduce the Earth's temperature appreciably?),

affordability (is it very expensive?), **availability** (when can it be used?), and **safety** (are there dangerous side effects?) Around the same time, Lenton and Vaughan (2009) go a little further and try to quantify the energy effectiveness of many geoengineering methods. Another interesting synthesis work is the one that summarizes a 2007 NASA Workshop on methods for reducing solar radiation (Lane *et al*., 2007). It is also worth highlighting a small popular book on solar geoengineering written by one of the great specialists in the field (Keith, 2013).

Most studies carried out in the last 20 years revolve around a single geoengineering method, increasing the Earth's albedo by injecting aerosols into the stratosphere. This method is based on the empirical observation that large volcanic eruptions, such as those of Pinatubo in 1991, significantly reduced the Earth's temperature for a certain time (Robock and Mao, 1995). Large explosive volcanic eruptions inject large quantities of S aerosols into the stratosphere and these particles reflect sunlight, increasing the Earth's albedo and therefore decreasing its temperature. The problem is that these eruptions not only reduced the Earth's temperature, but also had other unwanted effects (Trenberth and Dai, 2007).

Some studies on different geoengineering methods are provided in the following bibliography. Most are simulations of the effects of aerosol injection into the stratosphere, although there are also some on other methodologies (IPCC, 2005; Ridgwell *et al*., 2009; Köhler *et al*., 2010).

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