Emerging Scientists Supplementary Issue

Planet Earth Student Competition 2019

Shaina Eagle

On this increasingly warm Earth, something needs to be done to alleviate the symptoms of global warming. Rising temperatures have already had detrimental effects on our planet, and if nothing is done to combat one of the most major causes of warming- emission of greenhouse gases- then the situation will only get increasingly worse. Solar geo-engineering is designed not only to remedy the existing atmospheric pollution but prevent further harm.

The increased emission of greenhouse gases into Earth's atmosphere has caused significant damage to the planet. Greenhouse gases such as carbon dioxide, methane, and nitrous oxide trap solar radiation in the Earth's atmosphere, causing global and surface temperatures to rise. These increased temperatures have led to melting polar sea ice changing ocean circulations, rising ocean levels threatening coastal communities, shifting precipitation patterns affecting agriculture, and worsening weather phenomena that endangers lives around the world. And unfortunately, this dangerous trend of warming shows no signs of slowing down. According to the U.S. Environmental Protection Agency, between 1990 and 2010, net emissions of greenhouse gases by human activities increased 35% worldwide, which led the total warming effect of the Earth's climate to increase by 37% between 1990 and 2015. The significant reduction in greenhouse gas emissions necessary to stop climate warming may not happen. And even if it does, it may be too little, too late. One approach to reducing Earth's climate risk that is available right now is solar geo-engineering. Much of the buildup of greenhouse gases in the atmosphere

doi:10.1142/S252973251997006X

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and the warming it has caused is irreversible, so appropriate measures must be taken soon in order to prevent any future, and much worse, consequences.

GEOENGINEERING SOLUTIONS TO CLIMATE CHANGE

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1

Geo-engineering is split into two categories: carbon dioxide removal and solar radiation management. Carbon dioxide removal, also known as negative emissions technologies, aims to remove carbon dioxide and other harmful greenhouse gases from the atmosphere, thus helping reduce some of the detrimental effects these gases have on the planet's ecosystems. Methods of carbon dioxide removal are further classified as direct or indirect. Indirect removal includes natural processes such as reforestation and afforestation, which utilize plants' organic ability to remove harmful pollutants from the air. Direct removal encompasses a variety of techniques such as carbon capture and storage and ocean fertilization. Carbon capture and storage is an approach that is currently in limited use and works by sequestering carbon from large sources of waste like

¹ <https://geoengineering2012.wordpress.com/tag/carbon-dioxide-removal/>

fossil fuel plants and depositing it underground so that it will never have the opportunity to enter the atmosphere. Meanwhile, solar radiation management aims to reduce the amount of solar radiation absorbed into the atmosphere. Solar radiation management (SRM) is accomplished by making the atmosphere more reflective. Techniques of SRM involve installing man-made reflective surfaces on Earth, in the atmosphere itself, or even space. These reflective surfaces can include, but are not limited to, large sheets of polar sea ice, mirrors, or artificial clouds. Another method of solar radiation management is releasing synthetic aerosols such as sulfates which are self-levitating and designed to reflect solar radiation into the atmosphere. While geo-engineering is synthetic, whether in the form of negative emissions technology or solar radiation management, it still mimics phenomena witnessed in nature, such as when volcanic eruptions spew light-scattering aerosols into the stratosphere. In 1991, Mt. Pinatubo in the Philippines released ten million tons of sulfur that stayed in the stratosphere for months. Records have since shown that Mt. Pinatubo's eruption decreased Earth's temperature by an average of 0.5° Celsius for the subsequent years. Many SRM techniques are derived from natural events such as this and intend to help reduce Earth's climate risk through strategic intervention.

2

Critics have found many reservations when it comes to geoengineering, and some rightfully so. The reduction of greenhouse gases into the atmosphere in the first place is ultimately the best way to combat climate change, but opposition to geo-engineering fears that the possibility of alleviating the effects of global warming without having to stop harmful practices will justify not instituting policies that reduce emissions. Additionally, geo-engineering does not address the results that have already occurred from greenhouse gas emissions, primarily ocean acidification. Although it could help prevent further decreases in ocean pH levels in the future, geo-engineering does not treat the already unbalanced ecosystem. Another major concern

² Images captured by the Stratospheric Aerosol and Gas Experiment II aboard NASA's Earth Radiation Budget Satellite. The images represent aerosol optical depth in the stratosphere during four different time spans, ranging from before the June 1991 Pinatubo eruption to two years after the event. They demonstrate the volcanic plume's global-scale impact on climate.
<https://earthobservatory.nasa.gov/images/1510/global-effects-of-mount-pinatubo>

is that it may cause ozone depletion. However, the true limitations, as well as the possible achievements, of solar geo-engineering are relatively unknown. It is an aggressive approach, yes, but to an increasingly aggressive problem. Mitigation, particularly in the form of emissions reductions, is significantly important but steps must also be taken to combat what has already been done.

3

Therefore, this paper is not entirely dedicated to championing geo-engineering as the sole or even most promising method of managing climate change. However, geo-engineering, while aggressive, may be the only way to combat the severe implications of global warming caused by human activities. It may sound counterintuitive, but the only possible way to reverse, or at the very least decelerate, the decades of human interference with planet Earth may be further human intervention- in the form of geo-engineering. Solar geo-engineering will become a necessary measure to combat the worst outcomes of rising temperatures if mitigation efforts cannot quickly and effectively reduce the global temperature. As extreme weather, rising sea levels, and atmospheric pollution get worse and demand action, the most important solution to Earth's

³ A trapeze of strategies representing responses to anthropogenic climate change.
<https://www.frontiersin.org/articles/10.3389/fenvs.2018.00043/full>

problems will be having a thoroughly researched and internationally agreed upon method of adaptation. Before geo-engineering can become a reality, the social, ecological, and political impacts need to be assessed by qualified scientists and policymakers alike. Change is overdue. Talking about possible solutions has gone on long enough, and it is now time to set a serious course of action if anything is going to be done to reverse the critical threat of climate change.

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