

Geo-engineering and the Climate

Much has been made about whether the climate is changing and how much, if any, of it is due to human influence. As evidence continues to mount on the affirmative of anthropogenic climate change, the debate on that topic is fading while debate on what to do about it is on the rise. However, much of the talk has been on how to limit further warming and limit future greenhouse gas emissions from such sources as fossil fuels and even methane from the agricultural sector. However, this is the equivalent of deciding to start washing your hands after you already have the flu. Even if we were to completely cease all use of fossil fuels right now, climate models project that globally averaged temperatures are pretty much already locked into a 2°C warming relative to the pre-industrial average global temperature (AGT).¹ Combine that with the fact that after decades of debate on climate change, no real progress has been made in reducing CO₂ emissions, and it might be time that we, as a species, start looking to take the fight to global warming, as opposed to limiting policies to reducing future warming and patiently waiting for some new technology to save us.

There are two ways to change the climate. You can effect the amount of energy coming into the system, or you can change the amount leaving the system. It really is as simple as that. The sun emits radiation at a fairly short wavelength, due to its high temperature. This radiation is mostly transparent to our atmosphere, though approximately 30% of this incoming radiation is reflected off of clouds, ice, etc due to what is known as albedo. It is then absorbed by the earth and re-emitted as longwave radiation due to the relatively lower temperature of the earth. This longwave radiation is not transparent to the greenhouse gasses in the atmosphere who readily absorb much of it, re-emitting it equally up to space and back down to the surface.² Right now, human actions are increasing the amount of greenhouse gasses (GHG's) in the atmosphere, which reduces the radiation that escapes the atmosphere. We are also increasing the amount of aerosols in the atmosphere, which scatter and reflect incoming

solar radiation reducing the amount of radiation absorbed by the system; however, the extra energy being trapped is much greater than amount being reflected. These two process represent two forms of geo-engineering, even if it they weren't done deliberately. So, the question becomes, are there any actions that we can do to further limit the absorbed solar radiation (ASR) and/or increase the outgoing longwave radiation (OLR) to cool the climate system down? There are two main classifications of geo-engineering projects, those that limit ASR and those that increase OLR.

The first type of geo-engineering consists of decreasing the ASR. One of the most popular and well known potential geo-engineering solutions is to mimic the effects of a large volcanic eruption by injecting sulfates into the upper atmosphere. There is a well documented global cooling effect after large eruptions as aerosols, sulfates in particular, are forced high into the atmosphere which reflect 1% of solar radiation back into space. However, this effect is short lived, lasting only a few years, as gravity eventually pulls the sulfates back down to the surface.³ Therefore, it has been postulated that we do the same thing ourselves, artificially placing sulfates into the stratosphere. This would provide a fairly inexpensive and very near immediate fix for rising temperatures. David Kieth, of MIT, projects that 1 gram of fine sulfates injected into the stratosphere could offset the warming caused by a ton of CO₂ emissions.⁴ While sulfates are emitted by pollution from humans, it is important to note that most of these remain in the lower part of the atmosphere, known as the troposphere, and only have a lifetime of a few days before falling back down. Placing them into the stratosphere drastically increases their lifespan.⁵ Also, the smaller the particles, the more coverage you can get for the same mass while further increasing their lifespan as they would be lighter in mass.

However, this plan does not come without drawbacks. Increasing the level of sulfates in the stratosphere could have a negative impact on ozone, which primarily resides in the stratosphere. If it was perfectly evenly distributed, this would be no big deal, as such a small amount of ozone would be effected. However, realistically, there is no way to produce an even distribution. This could lead to localized pockets where the ozone layer is weak. Models also project that such a project could lead to

decreased precipitation in tropical regions by as much as a third. Such localized effects lead to the final and largest obstacle for sulfate seeding. Global ramifications implies that global cooperation would need to be had. Even if sulfates were to only be released over an individual country, they would spread over to other countries. Plus, many countries would blame any bad weather on the sulfates and try to claim reparations regardless of the validity of their claims. Nonetheless, should climate impacts increase to an unbearable level or approach a potential tipping point, such measures present a viable quick fix.^{4,6}

Spreading sulfates in the stratosphere is not the only way to decrease the ASR. There are several less controversial means to do this. One easy way to do is to use high albedo paints in our cities and urban areas. Cover roofs, sidewalks, and potentially streets with material that has a high albedo and the ASR would be decreased. Urban areas cover about 3% of the total land surface of the earth as of 2005.⁷ Given that urban materials tend to be very dark optically speaking, a high albedo paint could decrease the ASR by as much as 3% (this is assuming that every inch of urban area as of 2005 had an albedo of 0 and now has an albedo of 1). To put things in perspective, most models place the forcing from a doubling of atmospheric CO₂ relative to pre-industrial levels at 3.7 W/m².¹ That is, there would be 3.7 watts coming into the climate system (specifically the top of the atmosphere) for each square meter than there is coming out. Also, the average incoming solar radiation is about 342 W/m² of which approximately 30% is reflected, meaning about 240 W/m² is absorbed at the surface. If we decrease that number by just 1.5% that would approximately balance out the forcing from a doubling of CO₂. Granted, there are feedbacks in play already that would have to be accounted for as well, but the idea of high albedo paints and materials in urban areas is not so outlandish. Using more realistic numbers, a common average albedo for cities appears to be around 0.15. While initially, bright, albedo paints can dull over time. Good quality paints can maintain a value of around 0.65.²⁵ Even with the more realistic numbers, there can still be a large enough effect to counter a doubling of CO₂. There are a couple of downsides to this as well. First, keeping the surfaces light requires cleaning which would incur more

costs, and even then, the albedo would degrade over time, requiring replacement. While acrylic paints would be very cheap and are actually brighter than more higher end albedo paints, they lose their value quicker as well.²⁴

The second way to cool off the planet and combat the effects of climate change is to encourage more radiation to leave the system. For this approach there are two major categories, decreasing the concentration of GHG's and indirectly cooling the system, or encouraging heat to leave the system directly. The most common method and well publicized approach to sequester GHG's is to increase the activity of what is known as the biological pump. While trees and plants take in carbon dioxide from the atmosphere, most of that intake is temporary, being released when the biomass decomposes or is burned. Often overlooked is how much photosynthesis, and hence how much carbon fixing, occurs in phytoplankton in the ocean. However, when these organisms die off, they sink down. Many are either consumed or decompose while in the upper part of the ocean; however, once their remains, known as marine snow, reach about 1km of depth, they are for all intents and purposes removed from the system.² Hence, the carbon is pumped via a biological process down to the deep oceans where it remains. If we could increase the number of phytoplankton, then more carbon should be pumped down into the deep ocean, out of the atmosphere. The main way of accomplishing this is to add iron into iron-poor surface waters of the ocean. Given that iron is often the limiting nutrient in phytoplankton growth, the mere presence of iron will induce a phytoplankton bloom. Such processes occur naturally where upwelling of deeper water bring nutrients to the surface or near the coastlines where iron and other nutrients are introduced via river mouths. While certain blooms such as red algae can be detrimental to the ecosystem, such outcomes are not likely in deep water oceans where there are iron deficiencies. Plus, if the iron gets carried near shore, it will not have much of an effect as there is already abundant nutrients and the likely limiting factor of growth for phytoplankton is not iron. The biggest concern would be that the potential impact on the ecosystem the increase in phytoplankton could have. However, the scale of such a project would have to be quite large to equate to any real change in the ecosystem given

the presence of natural blooms. This leads to the major drawback of such an idea. While recent studies have shown that a surprisingly large percentage of the carbon made it to the deep, the total amount was quite small. In fact, if the entire southern ocean were to be used as a bloom (most of the proposed sites for this as well as research have occurred in the southern ocean), it would only sequester 1/6 of the carbon emitted into the air from fossil fuels in a year (this equates to approximately 71 g of carbon per square meter).⁸ Admittedly, tracking all of the carbon descended several hundred meters into the ocean over 10 square miles is not an exact science, the results do not look promising. While it likely wouldn't hurt to use the iron fertilization technique to help remove carbon from the atmosphere, it is not an end-all solution and should probably only be used as an auxiliary solution in conjunction with other solutions.

Another way to remove carbon from the atmosphere via natural means is by increasing forests and restoring wetlands. However, it is not as simple as growing more trees or plants. Unlike the phytoplankton, when terrestrial plants die, there is no long-term sink or reservoir to take them in. Instead, decomposition or fires releases most of the stored carbon back into the atmosphere. Therefore, in order to use forests as a carbon sink, you have to either increase the total net biomass on the earth, or keep the trees from decomposing. Recent studies, however, are showing that mature forests may actually be a net sink for carbon.⁹ In large part, this is due to increased productivity among forests due both to increases in CO₂ concentrations as well as nitrogen deposition, from the burning of fossil fuels, which acts as a fertilizer. However, quantifying this net intake has not yet been accomplished globally. From 1990-2005, the approximately 1.5 million square kilometers of forests in Europe took in about 100 Tg of carbon more each year than they released. This equates to about 67 g of carbon per square meter per year.⁹ For reference, 8.62 Gigatonnes of carbon were released in 2012.¹⁰ In order to break even, there would need to be about 129 million square kilometers of similar forest, or right about 25% of the entire earth's surface. Such a discovery then comes into conflict with the other way to utilize forests as a carbon sink, and that is to harvest the wood for use. Increasing the use of wood

products over a long enough time scale still wouldn't likely have a net decrease in atmospheric CO₂, but it could certainly increase the time that carbon spends locked up in organic matter, decrease the use of more carbon emitting resources such as production of concrete and steel, and would not be adding any carbon into the system from reservoirs that would normally keep it locked up for millions of years. To make any sort of policy on either method right now would be unwise given the lack of quantitative data at the moment. The best case is to try and optimize both. Forests that are not acting as a net carbon sink could be encouraged for harvesting while those that are a net sink can be preserved.⁹ A potential downside to increasing the forest cover on the planet is that it could lead to higher strain on non-forested environments. Agriculture would be constrained to using the same soils over and over while restriction of grassland type environments could lead to overgrazing.⁹ There are other benefits indirectly associated with increased forest production, which will be examined later on.

The second natural way to increase carbon sequestration is via wetlands restoration. While terrestrial biomass tends to decay, releasing carbon back into the atmosphere, wetlands are known for being anaerobic. The oxygen depleted waters that cover them retard decomposition of decaying plant matter.¹¹ In this way, carbon is being removed from the atmosphere, isn't going back into the atmosphere, is done in a natural way, and requires no human intervention other than the initial restoration. Plus, wetlands have been reduced by large numbers due to human population growth, so increasing them wouldn't be changing the ecosystem so much as it would be bringing it back to where it started. A study in Canada found that wetland restoration produces a net sink of 86 g of carbon per square meter per year.¹² By that standard, less than 20% of the earth's surface would have to be covered in wetlands as productive as Canadian wetlands to take in as much carbon as was released due to fossil fuels. However, a study over 5 years by the USGS in California found that their wetlands captured a staggering 3000 g of carbon per square meter per year over a period of 5 years.¹¹ At that rate, only 0.563% of the earth's surface would need to be converted to take in as much carbon as was being released by fossil fuels. Even another study in Florida everglades noted a net carbon sink of 241 g of

carbon per square meter per year.¹³ 7% of the surface would need to be converted at this rate of sequestration. While various studies have come up with varying rates, it seems pretty evident that wetlands are highly productive means of carbon sequestration for a minimal amount of effort. However, there is a certain caveat. Wetlands can also be notorious producers of methane, accounting for 20-40% of natural methane emissions.¹⁴ If more wetlands are restored, then it stands to reason that more methane will be released. In the absence of O₂ the decomposing microbes that are there still need oxygen atoms for their metabolism. Often turning to CO₂ and hence releasing methane. Luckily, there is a way to get around that. Salt water wetlands produce negligible amounts of methane, because the microbes have access to sulfates in the water. Moreover, both the Florida studies and the California USGS study were conducted in salt water wetlands. Therefore, there is reason to hope that if coastal wetlands are restored, then they can act as very productive sequesters of carbon while also not increasing the methane emissions. Even better is the idea that wetlands act as a buffer for the coastlines. They filter out much of the pollutants that terrestrial rivers carry, helping protect the oceans. They also can absorb much of the impact of flooding. So, as sea levels rise and hurricanes increase, the addition of more coastal wetlands can help limit flooding that would occur.¹⁵

The last main way to remove GHG's from the atmosphere, thereby allowing more radiation to escape, is with biochar. Instead of trying to sink dead autotrophs to the bottom of the ocean, storing carbon in wood products, or in a marsh, plant matter can be converted into more useful forms via a process known as pyrolysis. Biomass is heated to high temperatures in an oxygen deprived environment. Without the oxygen, combustion isn't possible, and the biomass is converted into biochar, which is basically coal, as well as bio-oils and syngas. The proportion in which each is created depends on the temperature used to char it.¹⁶ Furthermore, this process is a net energy gain. Meaning, the energy possible from the converted biomass is more than required to pyrolyze it (physics isn't broken, there was plenty of energy lost from the sun and such in order to create the biomass in the first place).¹⁷ The syngas and bio-oils can be used directly as a replacement for many types of fuel, or can even be

converted into biodiesel. Some places even use the syngas to power the pyrolysis in the first place. The biochar is very useful as well. Not only can it be used as a direct substitute for coal, but it can be placed into soil as a means to enhance agriculture. Depending on the quality of the biochar, adding it to the soil can increase water retention, reduce the acidity of the soil, and can act as a fertilizer. The char also acts as a filter in the soil, removing pesticides and metals while also reducing the leaching of nutrients from the soil. One possible application is the use of biochar in replacing slash and burn agriculture. Slash and burn techniques leave only 3% of carbon in the soils. If this was to be replaced by slash and char, then the soils could retain as much as 50% of the carbon, as well as the benefits listed above. Therefore, less deforestation is needed, and crop yields can be higher. Also, the carbon can stay in the soil for centuries.¹⁸ While this does appear to have a bright future, it is currently not cost effective. While more energy can be gained than costs to produce, storing the char in soil negates much of that energy. Bio-oils produced are very corrosive and need extra refining to be of much use. Also, you have the cost of collecting, processing and transporting, the biomass for pyrolysis. However, if carbon taxes become more mainstream and the price of fossil fuels continues to rise, there is certainly potential for this to become a very economically viable venture.¹⁹

Finally, it is possible to directly increase the heat lost to space by increasing the amount of rainfall. This increases the negative feedback known as the lapse rate feedback. Evaporation of water at the earth's surface requires a fair amount of energy. When water vapor rises, it eventually condenses, releasing the energy it took to evaporate higher into the atmosphere. Essentially, this acts as a radiation highway, allowing the energy to bypass several kilometers of greenhouse gasses.² Climate models have a tendency to underestimate precipitation which leads to a slight overestimate in surface temperatures.²⁰ There are two ways to do this. First, is by cloud seeding. Similar to the spreading of sulfates to increase the albedo, we can seed clouds with silver iodide or frozen carbon dioxide.²¹ However, it is difficult to measure how much rainfall was induced that would have otherwise remained in the atmosphere, if any. Furthermore, how much latent heat would be released by condensing water vapor compared to the

emissions required to seed the cloud, assumedly by plane, in the first place? However, there is another way. Trees. Apart from their previously listed benefits, trees soak up water from the soil, and then it evaporates through its leaves. Some studies have shown that afforestation (the planting of trees where there previously were none) can increase rainfall locally by 10-15% and reduce temperatures by 0.3 to 0.5°C.²² Apart from simply providing another source of water for evaporation, plants can actually see clouds and increase the aerosol albedo of the planet. Plants release gasses, the same gasses that give the forest its scent, that readily react with natural aerosols, increasing their size.²³ These larger aerosols reflect more incoming radiation due to their larger size, and also act as cloud condensation nuclei (CCN). Water vapor in the atmosphere needs something to condense on, otherwise it will remain a gas. Smaller aerosols allow for smaller droplets, but these aren't heavy enough to fall as rain usually. In general, these small, fine droplets are what make up clouds. If the number of droplets remains the same, but the amount of water vapor increases, then the droplets will get bigger, eventually forming rain.² One can actually seed clouds in such a way as to prevent rain if you seed them with a bunch of very tiny CCN's, then the water will evenly distribute and no drop will be big enough to fall. However, with the gasses from trees, these CCN's become larger, and help induce more rainfall. Moreover, warmer temperatures increase the production of these gasses further amplifying the negative feedback. However, these effects are all regional, and will likely not have a large impact on a global scale. Also, it is uncertain how much of an impact afforestation could have compared to the slight decrease in albedo. Forests are darker and absorb more incoming solar radiation than grasslands.²

In conclusion, no singular answer to climate change exists in the form of geo-engineering. It should also be noted that such projects should not be viewed as a solution to climate change. Instead, geo-engineering is merely a treatment of the symptoms of climate change. Ignoring the actual causes would just lead to more increasingly expansive geo-engineering. Many view the idea that such projects should be avoided since it may lead to policy makers using them as a crutch. However, the benefits of geo-engineering are far too great to ignore just because of the fear that employing such projects would

lead to ignoring the major problems. As mentioned before, even if fossil fuel emissions were to be entirely stopped today, we are still committed to a 2°C warming. Hence, cooling the planet off may not be a bad idea. The other main argument against geo-engineering projects is the unnaturalness of many of them and potential side effects. However, most of the projects outlined here are in fact very natural with minimal negative side effects. The three most beneficial projects would be to increase the albedo of urban areas, restore coastal wetlands, and try to increase forest cover. These provide high effect, low cost, and minimal bad side effects while each one providing auxiliary benefits as well.

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