RESTORING ARCTIC ICE: A MORE BENIGN CLIMATE INTERVENTION?

STEVEN ZORNETZER, ANTHONY STRAWA, AND TIMOTHY PLAYER

THE NEED FOR CLIMATE INTERVENTION

Our planet's climate is changing due to human-caused disruption of the balance between solar radiation absorption (heat gain) and heat loss into space. The heat loss is due to the natural reflection of solar radiation both at the planet's surface and by clouds in the atmosphere. Atmospheric absorption of surface thermal radiation also occurs. This absorption of thermal radiation is increasing due to huge emissions of carbon dioxide and other gases into the Earth's atmosphere since the beginning of the industrial revolution[1]. These gases, commonly called "greenhouse gasses" (GHG), trap heat in the atmosphere that would otherwise be reflected back into space. The net effect is a reduction in planetary heat loss while solar radiation heat gain continues, thus warming the planet. In its simplest form, this imbalance is the root cause of global warming (GW). The widespread emission of GHG from the burning of fossil fuels has resulted in an unintended geoengineering experiment involving the entire planet as Steven Schneider eloquently stated in his 1997 book, 'Laboratory Earth'[2]. The rapidity and magnitude of the changes to climate from these emissions has led many scientists to refer to the present time as the Anthropocene, meaning that human activity is one of the largest factors driving climate change and GW.

"How do we, as the species that caused this unintended global warming problem, solve the problem?"

The problem of global warming is a complex one, with many factors influencing the process. A major driver of global warming, of course, is the continued large-scale emissions of GHGs by human use of fossil fuels. Even if, miraculously, all fossil fuel use was halted tomorrow and new, clean and renewable sources of energy replaced these traditional energy sources, the global warming problem would continue for some time due to the enormous amount of GHGs humans have already put into the atmosphere. These gases persist for many years and in some cases many decades, continuing to trap heat[3].

So, the question is, how do we, as the species that caused this unintended GW problem, solve the problem? Perhaps before addressing this question directly, as we will below, it is important to understand the consequences of doing nothing.

The adverse impacts of GW and associated climate change are undeniably dangerous: intensified destructive storms, droughts, wildfires, sea level rise, and an intense decrease in biodiversity caused by habitat degradation. Together, these consequences threaten the material safety and food security of a growing human population[4].

Doing nothing to slow and potentially reverse GW is not an option. Human and economic suffering will be catastrophic. Cost estimates for climate change-related disasters and associated infrastructure, agricultural, economic and human health impacts by 2040 are staggering. In just the next two decades, these costs are estimated to be $54 trillion world-wide.

If we agree that we must put enormous effort into slowing and reversing GW, what must we do? First and foremost, we must quickly and dramatically reduce our GHG emissions. Doing so slowly and incrementally will most likely be too little too late. Unfortunately, in recent years human societies have been too slow to shift from carbon-based economies to renewable and/or non-carbon forms of energy production. Hopefully, the past will not be prologue for the future. If human-kind does not quickly change the basis of our energy sources and consumption dependencies, our children and generations to come, will suffer.

CLIMATE INTERVENTION STRATEGIES

We do not have the luxury of time to wait idly by and do nothing while decarbonization of our societies takes place too slowly to avoid a climate catastrophe. So, what can we do to mitigate GW in the near term to buy time? What tools are at our disposal?

We must find ways to proactively extract existing GHGs, primarily carbon dioxide, from the atmosphere. There are a number of natural methods of carbon sequestration which can be enhanced. For example, replanting forests to take advantage of increased photosynthesis to extract carbon dioxide from the air, modifying agricultural practices to store more carbon in the soil, enhancing processes to mineralize carbon dioxide, accelerating natural carbon cycles in the ocean by planting "ocean forests" of seaweed or phytoplankton which use photosynthesis to store and create energy[5].

While these natural carbon capture methods can be effective, they are also slow. Are there technological solutions, in conjunction with natural solutions, that might be effective? "Carbon capture and storage", describes such an emerging set of technologies[6]. The degree to which these technological approaches can be scaled and made cost effective is currently uncertain. Such methodologies require considerable research and development. If proven successful, carbon capture technologies, in conjunction with large scale natural approaches to carbon sequestration, should all be vigorously utilized.

"If proven successful, carbon capture technologies, in conjunction with large scale natural approaches to carbon sequestration, should all be vigorously utilized."

So far, we have discussed two important approaches to slowing and potentially reversing GW: (1) decarbonization, i.e., shifting from carbon-based energy economies to non-carbon- based energy economies and (2) carbon sequestration, i.e., accelerating removal of existing carbon dioxide from the atmosphere. There is a third approach which can potentially augment these other two. This approach is broadly described as "geoengineering".

The National Academy of Sciences has drawn a distinction between geoengineering and "climate intervention", meaning an action intended to improve the climate situation[7]. They define geoengineering as being associated with a broad range of activities beyond and including climate that implies a greater level of precision and control than might be possible. At the Arctic Ice Project (AIP), we agree with this distinction and will use this term in place of "geoengineering" in the remainder of this white paper.

Recently, climate intervention approaches have gained visibility as a potential avenue to mitigate the harmful effects of GW. Actions which shift the radiative forcing balance (i.e., the balance between solar energy absorption and reflection) are gaining interest in the scientific community. Two such methods, atmospheric aerosol injection and surface albedo (reflectivity) modification seek to increase the planet's reflectivity in order to offset the increase to net radiative heat gain currently caused by GHGs. Let's briefly contrast these two general approaches.

In the case of atmospheric aerosol injection, there are two predominant methodologies currently being explored. The first, Stratospheric Aerosol Injection (SAI), seeks to deploy large quantities of sulfur dioxide particles into the stratosphere to act as a reflective barrier against incoming sunlight. This approach is still considered very controversial due to the unknown potential unintended consequences of large-scale atmospheric deployment[8]. For example, it is feared that there could be wide-ranging negative consequences (e.g., droughts) in some areas due to unequal global impacts. At this time, small scale research deployments are being planned to learn more about the impacts of such an approach.

A second methodology associated with atmospheric aerosol injection is called Marine Cloud Brightening (MCB)[9]. This refers to increasing the reflectivity of marine stratocumulus clouds by spraying sea water in fine aerosols to atmospheric locations where such clouds form. These salt water aerosols would then provide cloud condensation nuclei which are highly reflective. By increasing the reflectivity of these marine clouds, a greater proportion of incoming solar radiation would be reflected back into space, contributing to an overall cooling effect of the planet. Currently, this research is on-going and includes modeling, field experiments and technology development. Similar criticisms to SAI have been made of MCB. In particular, it is currently unknown where the impacts of Marine Cloud brightening might be felt. Would they be localized or distant? If distant, how would the technology be governed in accordance with international treaties and the law of the sea?

Suggested applications of SAI and MCB to date have had the objective of offsetting a substantial amount of the heating due to GHG emissions. The problem is that neither technology can replicate the temporal and spatial features of GHG heating and so could result in unintended widespread climate and weather disruption.

"We do not have the luxury of time to wait idly by and do nothing while decarbonization of our societies takes place takes place too slowly to avoid a climate catastrophe."

In order to stabilize or reduce atmospheric concentrations of GHGs, and thus avoid the worst impacts of warming would require substantial and sustained reductions in greenhouse gas emissions. To date, little progress has been made toward achieving such a major reduction[11]. The prospect of atmospheric carbon dioxide removal (CDR) technologies being ready for affordable large-scale deployment and timely intervention is also not likely[12]. At the AIP, we believe that regional surface albedo modification (SAM) designed to strategically increase the reflectivity of Arctic sea ice, if proven safe and effective, could be deployed with few or no unintended consequences if the need arises. Clearly, more research and development must be conducted to understand better both SAI and MCB atmospheric aerosol injection approaches. Until we understand better the risk/benefit ratio of such techniques, we cannot make informed decisions about their utility.

The remainder of this White Paper describes one sea ice SAM approach in more detail. It distinguishes this approach from other climate intervention approaches and makes the case that SAM appears to be safe and effective with the potential to slow GW.

"The accelerating loss of sea ice is contributing to the very rapid warming of the Arctic."

SURFACE ALBEDO MODIFICATION

SAM seeks to counteract the absorption of thermal radiation by the atmosphere (greenhouse effect) with increase surface reflection of solar radiation at the surface. The objective of SAM is to make small changes to the environment and to take advantage of climate feedbacks to minimize the disruptions. Here, the methodology focuses on increasing the albedo or reflectivity of ice[13]. This is important because ice in the Arctic Ocean and land-based glaciers in the Arctic and the Himalayas have historically been a major source of Earth's cooling through significant reflectivity of solar energy. In recent decades, Arctic sea and land ice have been melting at alarmingly fast rates. The loss of such ice is reducing the planet's reflectivity and simultaneously increasing heat gain through greater absorption of solar energy by dark Arctic Ocean waters underlying summer ice loss when the sun shines 24 hours/day. The accelerating loss of sea ice is contributing to the very rapid warming of the Arctic. Today it is estimated that the Arctic is warming nearly three times faster than the rest of the planet. The goal of sea (and potentially land) ice albedo modification is to reduce the rate of ice loss and potentially even restore such ice to more historically normal conditions. The more ice that persists during Arctic summer months, the more solar reflectivity and the less planetary heating.

Why is loss of Arctic sea ice so important in GW? Loss of Arctic sea ice engages two feedback mechanisms that promote increased warming. First, ice is more reflective than open ocean. Loss of sea ice reduces the reflectivity of the surface allowing more solar energy to be absorbed by the ocean, leading to more heating which in turn leads to further sea ice loss. Second, sea ice provides a thermal barrier protecting the cold Arctic air from the relatively warmer ocean below, effectively insulating the ocean from the cold air. Loss of sea ice removes this insulation and the ocean warms the air which in turn melts more ice. These two mechanisms contribute to Arctic Amplification. The objective of sea ice SAM is to break these feedback loops, restore sea ice, mitigate warming over a larger region, and slow GW. The AIP has proposed a non-traditional technology for achieving sea ice SAM. This approach was not considered in the National Academy's review of Climate Interventions National Academy Press, 2015). Sea ice SAM seeks to increase the reflectivity of sea ice during the summer months to prevent or significantly slow ice melt. AIP's approach is local by design and therefore its impact is smaller and easier to control. The aim is to rebuild the highly reflective multi-year ice and slow GW.

"The objective of sea ice SAM is to break feedback loops, restore sea ice, mitigate warming over a larger region, and slow global warming."

AIP's concept is to increase the reflectivity of young ice by applying a thin layer of reflective hollow silica-glass microspheres onto the surface of the ice[14]. This treatment increases the reflectivity of ice by about 50 percent, reducing the absorption of solar radiation. The materials used in this treatment are nontoxic, consisting of silica (the primary material in sand, and most rocks). Biotoxicological testing to date, has shown no adverse impact on wildlife. A climate modeling study, designed to simulate the potential impact of the reflectivity modification scheme over the entire Arctic Ocean showed that yearly application of the material on the Arctic sea ice over the period 2000–2040 would cause ice volume to increase 0.5 percent to 1 percent per year, with increased ice thickness of 20 cm to 1 m[15]. The climate modeling also shows that a large part of the Arctic sees temperatures decreasing by more than 1.5°C after application. Modeling an Arctic-wide deployment was done to demonstrate the effectiveness of the technology and is not a realistic scenario for deployment. Strategies for more targeted deployment of these microspheres in smaller areas, for example in the Fram Strait, through which much summer ice export has been seen in the past several decades, may be a key leverage point for ice restoration. Preliminary modeling shows that treating roughly 1% of Arctic sea ice area is enough to make a significant difference in overall reflectivity and sea ice retention that extends beyond the immediate treatment area (submitted for publication). Since these approaches are local, they are easily reversible and have no known termination effects.

Today, all climate intervention approaches are considered with more or less skepticism by most in the climate change community. Concerns about governance, unintended consequences, scalability, cost and the so-called, "moral hazard", of such intervention approaches are quickly elicited when discussion arises. At AIP we are sensitive to these concerns. We believe that before any climate intervention can be considered, at a minimum these five questions should be addressed:

"AIP believes a major research and development effort is urgently needed to fully understand the safety, effectiveness, cost and potential unintended consequences of currently proposed climate intervention approaches."

1. Is the technology effective for its intended objective?
2. Is it environmentally safe?
3. What are the regional and global climate effects and how long do they persist?
4. Are the potential differential impacts of the intervention on different regions understood and can they be made equitable?
5. In case the technology needs to be terminated are there any termination effects?

It is our opinion that none of the climate intervention technologies discussed here has been studied well enough to answer these five questions. AIP is committed to addressing each of these questions. Our studies to date are encouraging and we continue to actively address these and other important issues. We differentiate our sea ice SAM approach from other climate intervention approaches mentioned above.

There are other proposed sea ice SAM technologies such as fall or winter surface ice flooding by pumping underlying sea water to let it freeze and thus thicken the ice[16]. This concept, while interesting, has not been subjected to any rigorous research and technology development as has AIPs approach described above. AIP's technology is estimated to be at Technology Readiness Level 3, meaning that the main features have undergone successful proofs of concept, including successful initial demonstrations of the effectiveness, practicality, and safety of the approach; and initial expert climate modeling has demonstrated the potential impacts of a proposed at-scale implementation over a strategically chosen area of the Arctic.

Considerably more research, modeling and engineering studies are needed before any of these different climate intervention approaches can be seriously considered for full-scale deployment. To date, no major deployments of any climate intervention approach have been attempted. Several small demonstration projects, in laboratories or small-scale deployments, have been carried out along with some modeling efforts. AIP believes, in agreement with a recent National Academy of Science report[17], that a major research and development effort is urgently needed to fully understand the safety, effectiveness, cost and potential unintended consequences of currently proposed climate intervention approaches. We need every effective and safe tool in the tool box to be ready for use if and when the time comes. The clock is ticking and the GW crisis is looming larger and larger. We must be ready.

REFERENCES

1. National Service Center for Environmental Publications, 2009, Report ID: 430F09086
2. Schneider, Stephen, Laboratory Earth, Published by Basic Books, 1997. ISBN-13:9780465072804
3. "NASA GISS: Science Briefs: Greenhouse Gases: Refining the Role of Carbon Dioxide". *www.giss.nasa.gov*. Retrieved 26 April 2016.
4. Siegmund, Peter; Abermann, Jakob; Baddour, Omar; Canadell, Pep (2019). *The Global Climate in 2015–2019*. World Meteorological Society. p. 3.
5. "Carbon Sinks: A Brief Review". *Earth.Org - Past | Present | Future*. Retrieved 2 December 2020.
6. Intergovernmental Panel on Climate Change, ed. (2014), "Near-term Climate Change: Projections and Predictability", *Climate Change 2013 - the Physical Science Basis*, Cambridge University Press, pp. 953-1028, doi:10.1017/cbo9781107415324.023.
7. National Research Council 2015. Climate Intervention: Reflecting Sunlight to Cool Earth. Washington, DC: The National Academies Press. doi:10.17226/18988.
8. National Academies of Sciences, Engineering, and Medicine. 2021. Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance. Washington, DC: The National Academies Press. doi:10.17226/25762.
9. *Salter, Stephen; Sortino, Graham; Latham, John (2008-11-13). "Sea-going hardware for the cloud albedo method of reversing global warming". Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences. 366 (1882): 3989–4006. doi:10.1098/rsta.2008.0136.*
10. IPCC, 2014: *Climate Change 2014: Synthesis Report*. *Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.
11. IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
12. National Research Council 2015. *Climate Intervention: Carbon Dioxide Removal and Reliable Sequestration*. Washington, DC: The National Academies Press. doi:10.17226/18805.
13. McGlynn, Daniel,17 January 2017), "One big reflective band-aid". *Berkeley Engineering*. University of California, Berkeley.
14. Field, L., Ivanova, D., Bhattacharyya, S., Mlaker, V., Sholtz, A., Decca, R., et al. (2018). Increasing Arctic sea-ice albedo using localized reversible geoengineering. Earth's Future, 6, 882–901. doi:10.1029/2018EF000820.
15. Ibid.
16. Desch, S. J. et al. (2017), Arctic ice management, Earth's Future, 5, 107–127, doi:10.1002/2016EF000410.
17. Op. cit. National Academies of Sciences, Engineering, and Medicine.