CESifo WORKING PAPERS

7586
2019

April 2019

A primer on weather and climate intervention for economists

Scott Knowles, Mark Skidmore

CESifo

Impressum:

CESifo Working Papers
ISSN 2364-1428 (electronic version)
Publisher and distributor: Munich Society for the Promotion of Economic Research - CESifo GmbH
The international platform of Ludwigs-Maximilians University's Center for Economic Studies and the ifo Institute
Poschingerstr. 5, 81679 Munich, Germany
Telephone +49 (0)89 2180-2740, Telefax +49 (0)89 2180-17845, email office@cesifo.de
Editor: Clemens Fuest
www.cesifo-group.org/wp

An electronic version of the paper may be downloaded
· from the SSRN website: www.SSRN.com
· from the RePEc website: www.RePEc.org
· from the CESifo website: www.CESifo-group.org/wp

CESifo *Working Paper No. 7586*
Category 10: Energy and Climate Economics

A primer on weather and climate intervention for economists

Abstract

There is limited public discourse and understanding about the history and science of weather and climate intervention, though scientists have researched, tested and implemented numerous methods of weather modification for six decades. Also, climate-related geoengineering is steadily gaining support as a means of combatting rising global temperatures. With climate change and associated increasing occurrence of extreme weather events, there has not been a more providential moment to consider the implications of anthropogenic, atmospheric intervention. This paper summarizes information about weather and climate intervention with the aim of answering the question: Why aren't more economists interested in evaluating weather and climate intervention activities?

Keywords: weather modification, cloud seeding, geoengineering, climate change, economic analysis.

Scott Knowles
67 Morrill Hall of Agriculture
North Central Regional Center for Rural Development, Michigan State University
USA - East Lansing, MI 48824-1039
knowle46@msu.edu

Mark Skidmore
Michigan State University
Department of Agricultural Economics
208 Agriculture Hall
USA - East Lansing, MI 48824-1039
mskidmor@msu.edu

A Primer on Weather and Climate Management for Economists

Contents

Introduction

A necessary step in conducting an economic analysis of weather and climate intervention activity is to first provide a summary of what is known about artificial weather and climate manipulation. The lack of knowledge and discourse among the general public in the United States (U.S.) is due, in large part, to limited media coverage of a growing number of publicly funded research projects in the U.S. and across the globe. Although governments the world over allocate funding to innovative research and experimentation in the weather and climate intervention arena, there is limited transparency about the myriad of inputs and outcomes of such activities.

It is important to distinguish between weather modification and geoengineering. NOAA describes weather as the sum of short-term observations of variables like air pressure, temperature, humidity and wind direction at a given time and place. However, climate may be best understood as the averages of aforementioned variables in a certain place over a long period of time. Generally, the objective of geoengineering is to alter the state of the Earth's climate, whereas weather modification aims to influence more localized weather events. Figure 1 conceptualizes the distinctions between geoengineering and weather modification. Elements of both will be discussed throughout this paper. Figure 1 illustrates two important dimensions of weather and climate intervention. The horizontal axis gauges the scale of intervention activity, ranging from local to global in nature. The vertical axis measures the degree to which interventions are temporary to more permanent/irreversible in nature. A weather modification activity such as cloud seeding can be thought of as an impermanent, localized intervention. Geoengineering is larger in scope and can even be global in nature, where interventions are not so easily reversed. For example and as discussed in greater detail later, solar radiation management through the injection of sulfate aerosols into the stratosphere may have long-run irreversible impacts.

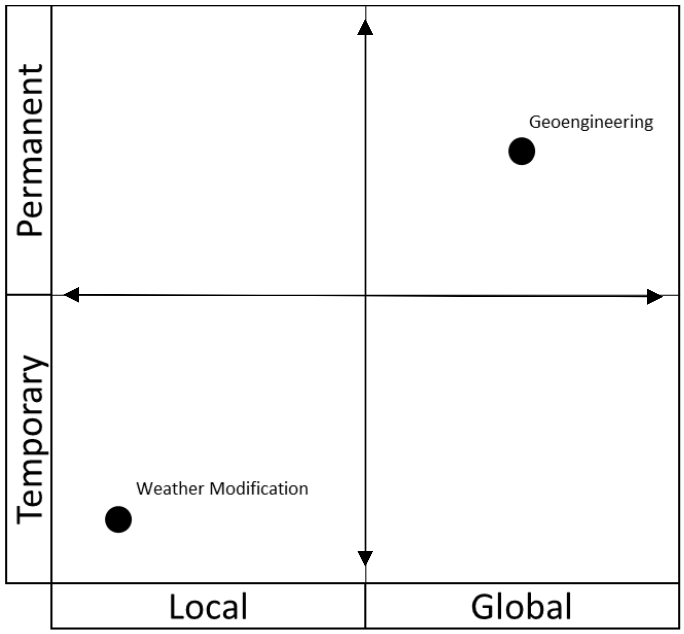

Figure 1: A diagram comparing weather modification and geoengineering

In 2014, the World Bank estimated that the United States' CO_2 emissions amounted to 5,254,279 kilotons – approximately 2% of global CO_2 emissions at that time (The World Bank, 2018). While CO_2 emissions affect the environment, we will not consider these and other similar types of indirect impacts of human activity in our discussion of weather and climate intervention. Over the course of modern human history there have been many claims, though few scientific ones, about the power of pluviculture (or rain enhancement). None of those claims, however, were demonstrated and accepted until the middle of the 20th century. On January 21st, 1948, Vincent J. Schaefer (assistant to Nobel Laureate, Irving Langmuir) and Bernard Vonnegut submitted their patent for a "Method of Crystal Formation and Precipitation" to the U.S. Patent Office. Their patent description states that, "by means of our invention; ice crystals may be formed in a supercooled cloud or in an air mass supersaturated with regard to ice, or in supercooled liquids" (Schaefer & Bernard, 1948). This is the first well-documented case of weather modification being conducted in the United States. The methods posited by these men set the groundwork for what is now known as "cloud seeding".

Thereafter, many in the scientific community became fascinated with the potential for anthropogenic modification of clouds or other manifestations of weather. In September 1965, a memorandum for President Lyndon B. Johnson titled "The Weather Services of the Environmental Science Services Administration," states that "It is clear that we must now press forward to improve our ability to detect, track, and predict severe weather hazards. It is equally clear that the time has come for us to move vigorously forward to explore the possibilities of modifying and controlling the weather in beneficial ways" (Connor, 1965).

Skeptics have questioned the effectiveness of documented U.S. weather modification projects through the 1960s such as Project Skyfire, where experimental silver iodide cloud seeding was conducted in Montana through the 1960s to “test effects on the lightning characteristics of thunderstorms and to develop methods to prevent forest fires caused by lightning” (Staats, 1972). Project Skywater, which was administered by the Department of the Interior Bureau of Reclamation, had the primary objective to learn “how to manage precipitation in water-deficient areas by seeding orographic (mountain-produced) clouds” (Rogers, 2009). Similarly, Project Stormfury was carried out between 1962 and 1983 to conduct research on hurricane modification through seeding techniques (Project Stormfury, 1962). Yet, even with mixed and unreliable outcomes, these projects were treated seriously, and required a substantial amount of public funding. Project Skywater had estimated costs of $28 million over a ten-year period (from 1962 to 1972).

Whether effective or not one thing has become clear; growing global interest in weather modification research elicited action from the United Nations, which opened the “Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques,” for signature in May 1977. The convention mainly states that all signors agree not to engage in “military or any other hostile use of environmental modification techniques...to any technique for changing – through the deliberate manipulation of natural processes – the dynamics, composition or structure of the Earth, including its biota, lithosphere, hydrosphere, and atmosphere, or of outer space” (United Nations, 1977). Henceforth, the United Nations made it clear that countries intending to harm others through deliberate manipulation of the environmental processes was an unacceptable and inappropriate use of these emerging technologies.

Our summary of the history of weather and climate intervention is inadequate insofar as we cannot fully describe in this paper the innumerable scientific advancements made since the convention. However, with this brief overview we can focus our attention on the recent past and present. Below, we consider recent developments in China where the government’s openness with and investment in weather and climate intervention activities appear to be unmatched.

A decade ago, the 2008 Olympic Games were hosted in Beijing, China. Leading up to the occasion, China’s government was prepared to ensure that the city’s sky was clear, and that no rain would fall over the “Bird’s Nest” stadium during opening ceremonies. The Beijing Weather Modification Office (BMO) actively tracked the region’s weather, and proceeded to use aircrafts, artillery, and rocket-launch sites around Beijing to inject incoming clouds with cloud-seeding agents. In doing so, the Chinese were successful in stopping rain from occurring over the Olympic Games, though some distant areas of the city received heavy rain (Pontin, 2008).

The continuing use of weather modification techniques by the Chinese government is thoroughly documented. In 2009, China kept the BMO – poised with eighteen aircraft and 48 fog-dispersal vehicles – on standby in days leading up to the National Day Parade to prevent any unwanted rainfall from interfering with the event (Watts, 2009). Later that year, Beijing experienced its earliest arrival of snow in ten years, which was made even heavier due to cloud-seeding activities conducted through the BMO. Director of the BMO, Zhang Qiang, stated that the opportunity to bolster the snowfall could not be missed because Beijing was "suffering from a lingering drought" (Canaves, 2009).

The Chinese government also made headlines this year with news regarding its largest ever scientific project in the Tibetan Plateau region. China intends to help solve drought problems in that region by constructing a network of furnace-like chambers, designed to emit cloud-seeding particles into the air, across an area the size of Alaska. The plateau acts like a conduit for the Yangtze, Mekong, and Yellow rivers – where an increase in rainfall would increase water levels of many tributaries. If the project is carried through to completion, Chinese researchers estimate the system may produce up to 10 billion cubic meters of rainfall each year (Nace, 2018). As the situation unfolds in China, we are afforded an opportunity to raise meaningful questions. Ought we to label the project in Tibet as geoengineering or weather modification? Returning to Figure 1, the case of Tibet may land closer to our interpretation of geoengineering than weather modification, at least in terms of scale.

As reported by the Chinese government, even more extreme and bizarre is the recent announcement by China of its plans to move rain clouds thousands of miles through an "atmospheric corridor" using unspecified satellite technology (CNAGA, 2017). With these examples of large-scale weather modification and geoengineering efforts coupled with significant costs and benefits, economists are poised for thoughtful evaluation of such programs. However, limited data access hamper such efforts in evaluation.

Thus far, this paper has introduced developments in both weather modification and climate geoengineering but has focused mainly on the uses of weather modification through cloud seeding efforts to induce rainfall. This approach was taken to establish the primary intuition behind weather modification, which is to affect cloud formation and water dispersion. However, it is also important to offer a review of the different types of known weather and climate intervention methods, each implemented to bring about different results.

Methods of Weather and Climate Intervention

It is now widely understood that development of human civilization affects the natural environment in numerous ways. For example, the creation of our urban centers creates what are known as "heat islands." Further, researchers have found that heat waves are, in fact, the most fatal kind of natural hazard among all weather extremes in the United States (Lim, J., 2018). As mentioned earlier, evidence suggests that carbon emissions, a by-product of economic development, is having an impact on global climate. The potential negative externalities of carbon emissions are difficult to measure and evaluate. While these issues are important, the objective of this paper is not to analyze the economic costs and benefits of human activities that indirectly impact the environment. Rather, our purpose is to investigate deliberate efforts to make changes to the environment. We have already noted that the United Nations defined environmental modification techniques as activity aimed at the deliberate manipulation of natural processes to change the composition or structure of the Earth and its many atmospheric layers. This definition will serve as grounding for all subsequent discussion. Next, we briefly summarize the primary types and purposes of geoengineering and then discuss weather modification purposes and methods.

Carbon Capture and Storage (Geoengineering)

Carbon capture and storage, which is sometimes labeled as carbon control and sequestration (CCS), refers to the process of collecting waste carbon dioxide (CO_2) from sources like fossil fuel power plants, and then transporting the waste to a storage site to be deposited where it cannot enter the atmosphere (usually a subsurface geological layer). This activity is also considered a type of climate change mitigation intervention. This method of geoengineering is a potential aid to reducing the impact atmospheric carbon dioxide has on climate. Some evidence of CCS feasibility was presented by the Intergovernmental Panel on Climate Change (IPCC). The panel found that applying CCS to a standard power plant could reduce CO_2 emissions to the atmosphere by 80-90% (Metz, Davidson, Coninck, Loos, & Meyer, 2005).

However, to capture the carbon dioxide, costly technologies must be adopted. The leading technology leverages the use of amines (aqueous solutions of alkylamines) to remove carbon dioxide (CO_2) from gases. The IPCC estimates use of this technology increase the energy needs for a coal-fired CCS plant by 25-40%, and other associated costs of implementation could increase cost per watt-hour energy produced anywhere from 21-91% for fossil fuel power plants (Metz et al., 2005).

With the immediate and extraneous costs related to CCS, it is not too not surprising that adoption by commercial power plants has been slow. However, ongoing research into carbon scrubbing and sequestration may reduce costs into the future. In addition, subsidization through tax incentives could help to make the cleaner power plant adopters competitive with non-adopting plants (Metz et al., 2005). Since CCS is implemented to reduce the widespread negative impacts associated with CO_2 emissions, it is considered as a type of geoengineering and not weather modification.

Solar Radiation Management (Geoengineering)

Increasingly, both scientists and citizens are concerned with the potential ramifications of global warming and climate change. Setting aside the debate about how much warming stems from anthropogenic origins, the IPCC recently released a report detailing the high likelihood that average global temperatures will increase up to 1.5 degrees Celsius above pre-industrial levels between the years 2030 and 2052. Further, research suggests that higher average temperatures will increase risks to health, livelihoods, food security, water supply, sea level rise, biodiversity, etc. ("Global Warming of 1.5 Degrees Celsius," 2018).

The goal of solar radiation management (SRM) is to slow the effects of global warming by reflecting sunlight back into space. This is done through the injection of sunlight-reflecting sulfate aerosols into the stratosphere, which theoretically mimics the similar effects that sulfate particles have on sunlight dispersion and subsequent temperature cooling after major volcanic eruptions. Two Harvard scientists, Frank Keutsch and David Keith, are planning to launch phase one of a geoengineering experiment called the Stratospheric Controlled Perturbation Experiment

(SCoPEx) during the first half of 2019. Their experiment will be the first of its kind; injecting calcium carbonate particles well above the surface of Earth in hopes of reflecting sun rays back into space (Aouf, 2018). Keutsch and Keith hold that their test will "pose no significant hazard to people or the environment." Calcium carbonate is a naturally occurring, nontoxic chemical; and if they decide to test sulfate in the experiment, the amount used would be less than the amount released as a byproduct of burning aviation fuel in one minute on a commercial airline flight (Keutsch, Keith, Dykema, & Burns, 2019). However, it is unclear what the health ramifications of greater sulfate injections may actually be if used on a global scale.

By comparing modern proposed SRM to similar natural experiments provided by the volcanic eruptions of El Chichón and Mount Pinatubo, Proctor et al. (2018) found that the "projected mid-twenty-first century damages due to scattering sunlight caused by solar radiation management are roughly equal in magnitude to benefits from cooling." This finding suggests that the SRM approach to alleviating damage caused by global temperature increases may have a zero net impact due to the negative insolation effect of stratospheric sulfate aerosols (SSAs) on specific crop. It is important to note that due to SRM data limitations, Proctor and his colleagues relied on volcanic eruptions to generate their estimates. Other researchers, like Heutel et al., have studied the incorporation of SRM into the Dynamic Integrated Climate-Economy (DICE) model. Their research mainly focused on the implications of uncertainty surrounding the climate and geoengineering but found that models ignoring SRM will over-prescribe abatement policies and drive up the carbon price. Yet, as SRM reduces temperatures but not carbon concentrations, it is considered an imperfect substitute for abatement (Heutel et al., 2018).

Extreme Weather Mitigation (Weather Modification)

A weather phenomenon that cause serious physical damage (in the case of hurricanes, hail, etc.), or results in the reduction of valuable resources (in the case of drought, famine, etc.) is considered extreme in nature. Moreover, evidence suggests that global warming has brought about irreversible damage and has increased the likelihood of harmful meteorological events such as hail and drought ("Climate change 2013: The physical science basis," 2013). It is fair to say that there is general societal and global agreement that reducing the occurrence and severity of these events is desirable.

Cloud seeding methods have been refined over roughly 80 years through research and experimentation ("Geoengineering the Climate System," 2013). The process generally involves the dispersion of particulate matter such as silver iodide into the air, providing nucleic surfaces for water to condense around. The moisture is already present in the air, but the insertion of foreign particles induces the dispersion of water (by increasing the level of condensation in the area) (Cotton, 1999).

In Canada, some of the most detrimental weather events are hail storms. Terry Krause, senior meteorologist at the Alberta Severe Weather Management Society, manages a crew that carefully observes approaching weather systems to evaluate the need for cloud seeding treatment. He says that his team treats "developing feeder clouds" using planes with flares containing silver iodide to reduce the mass of the hail developing in storm clouds by forcing precipitation to occur earlier, thereby decreasing the severity of the storm. According to Krause, the data shows that storms have increased in intensity over the years (Hughes, 2017).

There are also non-profit organizations such as The North American Weather Modification Council, which has a stated purpose to "advance the proper use of weather modification technologies through education, promotion and research" ("NAWMC Mission Statement," 2019). In the U.S., there are many state water conservation and management agencies that are also involved in cloud seeding operations. In North Dakota, the North Dakota Cloud Modification Project (NDCMP) was found to reduce hail damage by 45%, which translated into saving millions of dollars in crop value which would have otherwise been lost ("Economic Impact of Reducing Hail and Enhancing Rainfall in North Dakota," 2008). NDCMP works every summer to use cloud seeding to reduce hail damage and increase rainfall in an area spanning 7.4 million acres across the state. In 2008, Larry Leistritz and Dean Bangsund at North Dakota State University estimated $12 to $19.7 million in direct annual benefits attributed to the NDCMP – a program which had estimated costs of around $731,000 at that time ("Economic Impact of Reducing Hail and Enhancing Rainfall in North Dakota," 2008).

At the University of Geneva, J-P Wolf has conducted experiments to improve understanding of the power of ultrashort lasers to modulate cloud nucleation, fog dispersion, or even lightning. (Wolf, 2018) His findings, which built upon inventions patented in the early 90s (Diels & Zhao, 1992), show promise. Still, Wolf acknowledges that it may be some time before such new technologies can be implemented in a cost-effective, widespread, and safe manner. Moreover, there exist many other patented methods and inventions pertaining to weather modification and climate intervention, including but not limited to disrupting hurricanes and diminishing wind speed (Cordani, 2001), altering solar absorption patterns (Eastlund, 1987), leveraging solar-powered satellite systems to alter the composition of earth's atmosphere (Chen, 1998). Despite these potentially viable alternatives, cloud seeding – in its many forms – appears to be the dominant approach used to alter a variety of atmospheric processes. Yet, the United States has no acknowledged federal agency like that of the Chinese government's China Meteorological Administration explicitly engaging in geoengineering and weather modification efforts.

Rainfall Enhancement (Weather Modification)

Cloud seeding is a process by which a mass of foreign particles, such as silver iodide, dry ice, or table salt (in the case of hygroscopic seeding), are introduced into the atmosphere as potential targets upon which water vapor can settle and crystalize. Agents such as silver iodide are released from flares on jets, rockets, or ground furnaces (depending on the type of seeding requirements). Seeding must be targeted at a location where there is already a strong potential for or existing convective clouds to be successful. Depending on the temperature, the cloud may be induced to precipitate rain, hail, or snow. Worthy of noting, the literature does not indicate that the trace amounts of silver iodide being dispersed into the atmosphere for cloud seeding has any adverse effects on human or environmental health; the quantity of silver iodide used is well within the EPA and FDA standards (LaCross, 2013).

Cloud seeding to improve the conditions necessary for greater rainfall is now widely implemented across the globe. Indeed, the enhancement of rainfall can affect countless variables which are of interest to society. Access to clean drinking water, production of agricultural commodities, and upkeep of natural habitats all hinge on the amount of rainfall in any given period. For these reasons, generating rainfall through weather modification is considered by many to have the potential to combat some of the problems associated with unfavorable weather conditions and climate change.

In the private sector, companies like Weather Modification, Inc. have taken advantage of the global demand for weather modification services. Based out of Fargo, ND, Weather Modification, Inc. has worked for clients in 19 countries; consulting and working on projects ranging from rainfall enhancement, to hail suppression, to atmospheric assessment and evaluation ("Weather Modification Incorporated: Clients and Projects," 2019).

Meanwhile, research in the public sector varies greatly in ownership and accountability. A wide range of academic universities have programs specifically focused on the study of geoengineering, but not necessarily weather modification. For instance, Harvard and Oxford universities both have funded geoengineering departments, which focus on carbon and solar geoengineering research for the sake of counteracting climate change. However, these initiatives do not appear to explicitly study weather modification.

Other countries, however, have established central government agencies responsible for the advancement of weather modification activities. The UAE's National Center of Meteorology claims to use cloud seeding to study environmental pollution, evaluate urban planning projects, and participate in the field of agriculture ("Cloud Seeding," 2018). In South Africa, researchers have found "convincing evidence of increases in the radar-measured rain mass from seeded storms when compared to the control or unseeded storms" using the hygroscopic seeding method below convective storms (Mather, Terblanche, Steffens, & Fletcher, 1997). This year, the China Meteorological Administration (CMA) is celebrating sixty years of weather modification research and operations. The CMA implements a weather observation system made up of 34,000 weather stations and possesses roughly 6,500 antiaircraft artillery (re-purposed for cloud seeding), fifty aircraft, 8,200 rocket systems, and employees anywhere from 30,000 to 50,000 Chinese citizens, both amateur and professional (Liu & Hao, 2018).

As mentioned earlier, China has been investing resources into researching rainfall enhancement around the Tibetan Plateau in a project area which has been described as "three times the size of Spain" (Chen, 2018). The project aims to increase rainfall in the region drastically by creating a network of highly efficient furnace chambers which will burn solid fuel to produce silver iodide and provide the particles necessary for cloud formation in the arid plateau. A ground-based weather modification project of such magnitude is unprecedented, thus providing economists with a unique opportunity to analyze potential economic impacts of this project. Finally, as reported by the Chinese government, China recently announced plans to move rain clouds thousands of miles through an "atmospheric corridor" using unspecified satellite technology (CNAGA, 2017). It appears that China is increasingly placing greater emphasis on using sophisticated geoengineering technology to address its water issues.

Evaluating Ongoing Weather and Climate Intervention Activity

Having summarized known weather and climate intervention efforts, we now turn to a discussion of why such activities have not captured the interest of more economists. While there is emerging research evaluating the societal costs and benefits of proposed geoengineering in the context of climate change mitigation, research on the economic aspects of weather modification was mostly published in the 1960s and 1970s and has for the most part not been reconsidered in recent years. In 1965, the Rand Corporation researched the economic potential for weather modification to reduce unfavorable conditions (like hail, lightning, storms, fog, etc.), or produce more sunshine or an increased water supply (Rapp, 1965). The paper addressed accounting and research costs related to weather manipulation activities, highlighting the difficulty of estimating the value of additional water. Later, in 1966, a national weather modification program was recommended to the U.S. Federal Council for Science and Technology by the Interdepartmental Committee for Atmospheric Sciences. The memorandum noted the "potential dollar savings in lessening destructive effects of weather, and the potential gains in enhancing the beneficial effects, are so great that expenditures of appreciable dollars on weather modification research and application can be justified (Newell, 1966)."

A few years later, the American Water Resources Association examined the economic consequences of weather modification in the Colorado River Basin in 1973, considering direct and indirect costs of implementation. They concluded that the "evidence suggests weather modification as an economically feasible means of providing additional water for the Colorado River Basin (Rudel, Stockwell, & Walsh, 1973)." For the most comprehensive approach to the economics of weather modification, one looks to a report published in 1979 by Dr. Steven Sonka of the University of Illinois. He investigated direct and indirect effects of weather on multiple sectors of the economy, evaluating how precipitation augmentation and hail suppression impacts agriculture. Nearly forty years ago, Dr. Sonka concluded that the operational costs of weather modification were small relative to the high gross benefits, but that the indirect costs may be great (for instance, snowpack augmentation by increased precipitation may increase snowfall downwind, potentially attributing to greater need for snow removal services) (Sonka, 1979).

As previously discussed, the two prominent applications of weather modification are extreme weather mitigation such as hail suppression and rainfall enhancement, both of which use similar processes to achieve their desired results. Of fundamental importance is the evaluation of the effectiveness of such weather modification efforts.

Economists have used many approaches and techniques to assess the impacts of naturally occurring extreme weather events on a range of economic outcomes (Skidmore, 2017). These methods include a range of modelling and simulation techniques to econometric analysis. There has been much focus on the impacts of natural disasters, and the methods employed by economists studying such topics could readily be applied to evaluate weather modification efforts.

Unfortunately, weather and climate intervention efforts are more difficult to study due to the lack of publicly accessible data related to its implementation. While the IPCC calls for further research into solar geoengineering, and the experiments to test hypotheses are beginning to gain widespread approval, experiments necessary to test the possibilities of weather modification are lacking the attention they deserve. One of the goals of this report is to bring the issue to the attention of more researchers with the hope that a call for greater transparency will result in data being made available in order to conduct the needed analyses of these programs.

Conclusion

The proclivity for humans to interfere with nature is nothing new. However, it was not until the mid-20th century that viable weather modification applications began to be developed. More recently, there has been a growing interest climate geoengineering – which has recently garnered the attention of UN policymakers as a viable option to combat matters related to climate change. Weather modification has been implemented across the globe to target the direct needs of communities to suppress damages from extreme weather events and enhance precipitation to meet agricultural needs. Yet, the lack of economic evaluation of weather and climate intervention efforts is troubling. It seems that there are potential net societal benefits of weather and climate intervention, and yet there is relatively little peer reviewed evaluation of such efforts. For example, why did most of the economic research in the United States on weather modification largely dissipate in the late 1970s? Why do other countries have dedicated national level weather/climate intervention agencies, while the U.S. does not acknowledge any similar federal agency?

In this paper, we have discussed: (1) a brief history of weather and climate intervention research and activity, (2) a summary of the purposes and methods used in both weather and climate intervention efforts, and (3) a call for greater data access and more research by economists in this arena. Our goal with this paper is to call greater attention to the rapidly expanding use of technology to manipulate both the weather and the climate. For example, access to data is critical to properly research the effectiveness of cloud seeding solutions across the globe, whether that be in China, the United States, or elsewhere. As China invests substantial funding into programs which are likely to cause ripple effects across multiple economies, interested and influential researchers can to press for greater transparency and access to information. Moreover, international governing bodies such as the United Nations may have the power to collect a detailed inventory and motivate systematic evaluation of ongoing weather and climate intervention efforts globally. We believe this should be accomplished before considering or recommending any further large-scale geoengineering solutions to problems such as climate change.

Currently, advanced cloud seeding research – funded by the National Center for Atmospheric Research, sponsored by the National Science Foundation – is being conducted in Idaho. The Seeded and Natural Orographic Wintertime Storms: Idaho Experiment (or, SNOWIE, for short) has the primary objective of addressing the effectiveness of orographic winter precipitation enhancement through glaciogenic cloud seeding ("Seeded and natural orographic wintertime storms: The Idaho experiment (snowie)," 2019). Such an ambitious project creates hope that, in the future, economists will have access to more accurate scientific data that can be used to assess the effectiveness of precipitation augmentation practices.

Economists play an important role in the understanding of large-scale weather and climate intervention projects such as the one manifesting in Tibet. If such an enormous project continues to carry forward without economic analysis or critical assessment, what other large scale projects may be ventured into without multidimensional consideration and inclusion of the public as part of the deliberation process? We hope that this paper brings previously misunderstood, or unheard-of facts to attention, and that readers are both galvanized and better equipped to investigate the evolving landscape of weather and climate intervention.

References

Aouf, R. S. (2018). First geoengineering experiment to dim the sun on track for 2019. dezeen. Retrieved 2019-01-15, from https://www.dezeen.com/2018/12/11/first-solar-geoengineering-experiment/

Canaves, S. (2009). Beijing snow, man made in china. The Wall Street Journal. Retrieved 2019-01-14, from https://blogs.wsj.com/chinarealtime/2009/11/02/beijing-snow-man-made-in-china/

Chen, F. (1998, 6). Use of artificial satellites in earth orbits adaptively to modify the effect that solar radiation would otherwise have on earth's weather. USPTO. (US Patent 5,762,298)

Chen, S. (2018). China needs more water. So it's building a rain-making network three times the size of Spain. South China Morning Post. Retrieved 2019-01-14, from https://www.scmp.com/news/china/society/article/2138866/china-needs-more-water-so-its-building-rain-making-network-three

China National Administration of GNSS and Applications (2017). China launches engineering development of satellites and rockets of "Tianhe Project." Retrieved 2019-03-16, from http://en.chinabeidou.gov.cn/c/1289.html

Climate change 2013: The physical science basis. (2013). Intergovernmental Panel on Climate Change. Retrieved 2019-01-15, from https://www.ipcc.ch/report/ar5/wg1/

Cloud seeding. (2018). National Center of Meteorology. Retrieved 2019-01-14, from http://www.ncm.ae/en/details.html?id=825&lid=1475 (Ministry of Presidential Affairs)

Connor, J. T. (1965). The weather services of the environmental science services administration [Memorandum]. Retrieved 2019-01-12, from https://www.cia.gov/library/readingroom/docs/CIA-RDP68R00530A000200110020-2.pdf

Cordani, P. (2001, 11). Method of modifying weather. USPTO. (US Patent 6,315,213)

Cotton, W. R. (1999). Weather modification by cloud seeding-a status report 1989-1997. In H. V. Storch & G. Flöser (Eds.), (p. 139-160). Berlin, Heidelberg: Springer. (*Anthropogenic Climate Change. GKSS School of Environmental Research*)

Diels, J. C., & Zhao, X. M. (1992, 12). Discharge of lightning with ultrashort laser pulses. USPTO. (US Patent 5,175,664)

Economic impact of reducing hail and enhancing rainfall in North Dakota. (2008). North Dakota Atmospheric Resource Board. Retrieved 2019-01-15, from http://www.swc.nd.gov/arb/ndcmp/economic.html

Eastlund, B. (1987, 8). Method and apparatus for altering a region in the earth's atmosphere, ionosphere, and/or magnetosphere. USPTO. (US Patent 4,686,605)

Geoengineering the climate system. (2013). American Meteorological Society. Retrieved 2019-01-14, from https://www.ametsoc.org/ams/index.cfm/about-ams/ams-statements/statements-of-the-ams-in-force/geoengineering-the-climate-system/

Global warming of 1.5 degrees Celsius. (2018). Intergovernmental Panel on Climate Change. Retrieved 2019-01-14, from https://www.ipcc.ch/sr15/

Heutel, G., Moreno-Cruz, J., & Shayegh, S. (2018, 1). Solar geoengineering, uncertainty, and the price of carbon. *Journal of Environmental Economics and Management*, 87, 24-41.

Hughes, J. (2017). How Alberta manages severe summer weather. Global News. Retrieved 2019-01-14, from https://globalnews.ca/news/3514775/alberta-severe-weather-summer/

Keutsch, F, Keith, D., Dykema, J., & Burns, L. (2019). Stratospheric Controlled Perturbation Experiment (SCoPEx). Keutsch Research Group. Retrieved 2019-03-16, from https://projects.iq.harvard.edu/keutschgroup/scopex

Knox, P. (2018). China 'will move clouds and make it rain in different places using satellites' in terrifying weather control plan. The Sun. Retrieved 2019-01-15, from https://www.thesun.co.uk/news/7682561/china-weather-control-plan-satellites/

LaCross, N. (2013). Concerns regarding silver iodide cloud seeding. Utah Department of Health. Retrieved 2019-01-15, from http://health.utah.gov/enviroepi/appletree/technicalassists/Silver_Iodide_Cloud_Seeding.pdf

Lim, Jungmin. 2018. "Socio-Political Nature of Disaster Impact: Tornadoes, Floods, and Extreme Heat." Order No. 10242859, Michigan State University. http://ezproxy.msu.edu.proxy2.cl.msu.edu/login?url=https://search-proquest-com.proxy2.cl.msu.edu/docview/2092320248?accountid=12598.

Liu, S., & Hao, J. (2018). 60 years of weather modification in china. China Meteorological News Press. Retrieved 2019-01-15, from http://www.cma.gov.cn/en2014/news/Features/201809/t20180913_477849.html

Mather, G., Terblanche, D., Steffens, F., & Fletcher, L. (1997). Results of the South African Cloud-Seeding Experiments Using Hygroscopic Flares. *Journal of Applied Meteorology and Climatology*, 36, 1443-1447.

Metz, B., Davidson, O., Coninck, H. d., Loos, M., & Meyer, L. (2005). Carbon dioxide capture and storage. Intergovernmental Panel on Climate Change. Retrieved 2019-01-14, from https://archive.ipcc.ch/pdf/special-reports/srccs/srccs_wholereport.pdf

Nace, T. (2018). China is launching weather-control machines across an area the size of Alaska. Forbes. Retrieved 2019-01-14, from https://www.forbes.com/sites/trevornace/2018/05/10/china-is-launching-a-massive-weather-control-machine-the-size-of-alaska/#43b3b8816315

NAWMC mission statement. (2019). North American Weather Modification Council. Retrieved 2019-01-15, from http://www.nawmc.org/

Newell, H. E. (1966). A recommended national program in weather modification. Interdepartmental Committee for Atmospheric Sciences.

Pontin, M. W. (2008). Weather engineering in china. MIT Technology Review. Retrieved 2019-01-14, from https://www.technologyreview.com/s/409794/weather-engineering-in-china/

Proctor, J., Hsiang, S., Burney, J., Burke, M., & Schlenker, W. (2018, 8). Estimating global agricultural effects of geoengineering using volcanic eruptions. *Nature*, 560, 480-483.

Project Stormfury. (1962). National Oceanic and Atmospheric Association. Retrieved 2019-01-14, from http://www.aoml.noaa.gov/hrd/hrd_sub/sfury.html

Rapp, R. R. (1965, 4). Some economic aspects of weather modification. Western Snow Conference.

Rogers, J. S. (2009). Project skywater [Bureau of Reclamation Project]. Retrieved 2019-01-14, from https://www.usbr.gov/history/ProjectHistories/Project_Skywater_D1%5b1%5d.pdf

Rudel, R. K., Stockwell, H. J., & Walsh, R. G. (1973, 2). Weather modification: An economics alternative for augmenting water supplies. *Water Resources Bulletin*, 9, 116-128.

Schaefer, V. J., & Bernard, V. (1950, 10). Method of crystal formation and precipitation. USPTO. (US Patent 2,527,230)

Seeded and natural orographic wintertime storms: The Idaho experiment (snowie). (2019). Research Applications Laboratory. Retrieved 2019-01-15, from https://ral.ucar.edu/projects/seeded-and-natural-orographic-wintertime-storms-the-idaho-experiment-snowie

Skidmore, M. (2017). *The Economics of Natural Disasters*. The International Library of Critical Writings in Economics. Northhampton, MA, USA: Edward Elgar.

Sonka, S. J. (1979). Economics of weather modification: A review. *Illinois State Water Survey*.

Staats, E. (1972). Cloud-seeding activities carried out in the United States [Memorandum]. Retrieved 2019-01-14, from https://gao.justia.com/national-science-foundation/1972/5/cloud-seeding-activities-carried-out-in-the-united-states-under-programs-supported-by-the-federal-agencies-b-100063/B-100063-full-report.pdf

Swanson, E.R., Huff, F. A., Changon, A. (1972, 1). Potential benefits of weather modification for Illinois agriculture. *Illinois Agricultural Economics*, 12, 31-36.

The World Bank, I. S. (2018). *Co2 emissions from transport (% of total fuel combustion)* [Data File]. Retrieved 2019-01-11, from https://data.worldbank.org/indicator/en.co2.tran.zs

United Nations, G. A. (1977). Convention on the prohibition of military or any other hostile use of environmental modification techniques. Retrieved 2019-01-15, from http://www.un-documents.net/enmod.htm

Watts, J. (2009). China's largest cloud seeding assault aims to stop rain on the national parade. The Guardian. Retrieved 2019-01-14, from https://www.theguardian.com/environment/2009/sep/23/china-cloud-seeding

Weather modification incorporated: Clients and projects. (2019). Weather Modification Incorporated. Retrieved 2019-01-15, from http://weathermodification.com/

"What's the difference between weather and climate?" National Centers for Environmental Information (NCEI). Retrieved 2019-03-16, from www.ncei.noaa.gov/news/weather-vs-climate#

Wolf, J. P. (2018). Short-pulse lasers for weather control. *Reports on Progress in Physics*, 81(2), 026001. Retrieved from http://stacks.iop.org/0034-4885/81/i=2/a=026001

Xinhua. (2008). Beijing disperses rain to dry Olympic night. China Daily. Retrieved 2019-01-14, from http://www.chinadaily.com.cn/olympics/2008-08/09/content_6919493.htm