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Membership information is available by contacting the WMA Association at the Riverton, Utah address shown above or by visiting www.weathermodification.org.

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COVER PHOTO: A commercial agricultural aircraft with aerial electrostatic system for seeding clouds. Submitted by Arquimedes et al. as part of the technical submission titled, Texas Cloud Seeding Experiment Using Electrically Charged Drops, presented herein.

THE WEATHER MODIFICATION ASSOCIATION

The Weather Modification Association was organized in 1950 to develop a better understanding of weather modification among program sponsors, the operators and members of the scientific community. In 1966, the first suggestion for a professional journal was proposed and Volume 1, No. 1, of the Journal of Weather Modification was published in March 1969. This historic publication now includes 56 volumes (58 issues).

Originally called the Weather Control Research Association, the name of the organization was changed to the Weather Modification Association in 1967. During its long history, the Association has:

- Pressed for sound research programs at state and federal levels.
- Promoted a better understanding of weather modification for beneficial use.
- Acted as a disseminating agent for literature.
- Provided extensive testimony before many federal, state and local committees and agencies in regard to all aspects of weather modification research and operations.
- Assumed an active role in the promotion of policy statements concerning all aspects of weather modification.
- Developed active positions on ethics, minimum standards for operations, and a strong certification program for operators and managers.
- Published the Journal of Weather Modification, the only professional journal in the world totally dedicated to the operational, societal, economic, environmental, legal and scientific aspects of weather modification.

The Journal is published annually. Its articles are related to weather modification research, operations, technology including instrumentation, with a historical emphasis on operations. Papers are always welcome for consideration in either the scientific papers, or technical notes and miscellaneous paper sections. The technical notes and miscellaneous section has technical notes and possibly information about the Journal, messages from the Weather Modification Association, 'In Memory' notes about people in the weather modification community, and member comments about relevant weather modification community topics. A nominal charge of $100 per page or $2700 USD per 3000 words plus extra charge for figures, tables, equations, and copy editing will be charged for each paper published in JWM's final double-column format. This fee is charged for all papers, foreign and domestic.

Additional information on the individual classes of membership can be found in the Articles of Incorporation found at http://www.weathermodification.org.

Applications for membership on a calendar year basis, as well as additional information, can be obtained by writing to WMA at the permanent address of the Association:

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President’s Message

As we navigate an increasingly complex landscape, I am reminded of the strength and resilience of our industry and the professionals who dedicate themselves to advancing weather modification science. The challenges we face today are not just operational but also societal. Misinformation and conspiracy theories about cloud seeding and weather modification continue to spread, creating unnecessary hurdles for those working in this field. We have also seen a growing number of legislative efforts aimed at restricting or banning cloud seeding, often based on misconceptions rather than science.

Despite these challenges, our operators and researchers continue to deliver high-quality work, maintaining the integrity and effectiveness of weather modification programs. Their dedication ensures that we can continue to provide vital services—enhancing water supplies, mitigating drought conditions, and supporting agricultural sustainability. To those who work tirelessly in the face of adversity, I extend my deepest gratitude. Your commitment to excellence is what keeps this industry moving forward.

Beyond weather modification, we are witnessing an alarming trend: the erosion of trust in science. From climate research to weather forecasting, skepticism fueled by misinformation is leading to misguided policies and public uncertainty. The best way to combat this is through unity. As an industry, we must come together, collaborate, and support one another. We all share a common goal—to advance the science and application of weather modification for the benefit of society.

The Weather Modification Association has always been a hub for knowledge sharing, collaboration, and advocacy. Now, more than ever, we must leverage our collective expertise to engage with policymakers, educate the public, and reinforce the credibility of our work. By standing together, we can ensure that science prevails over speculation and that our industry continues to thrive.

Thank you for your dedication, resilience, and commitment to our shared mission. Let us move forward with unity and purpose, ensuring that our work continues to make a positive impact on communities around the world.

Sincerely,

Jonathan A. Jennings
WMA President, 2024

Editor’s Message

The JWM Volume 56 ended up with 3 technical notes and 1 miscellaneous contribution or comment, plus the editor’s message. One of the notes was derived from a meeting presentation and one was not from a meeting presentation. The comment relates to the NOAA Office of Oceanic and Atmospheric Research (OAR) public comment on weather modification. The latter was sent to the editorial board and beyond. Please feel free to submit your comments about the OAR public Comment requirement by NOAA to the JWM Editor. The comments could be subject to a page or total word charge as decided by the board. The JWM goal continues for more papers, without the need to include the editor’s or President’s message as such.

The journal is an integral part of the WMA! It facilitates the critically needed communication of our operational and developmental activities within and beyond our organization. Proceeds from the JWM support WMA activities. Each JWM scientific article, technical note/short contribution has a unique DOI tag giving it global accessibility.

Please consider submitting a paper, for example, a “short” contribution or technical note based on a presentation at our WMA meeting, student research project report, or an operational project report converted to the JWM paper format for example. If in doubt about whether a paper might be considered publishable, then send a quick query to the JWM editor. Submissions of relevant non-published scientific articles, conference presentations or extended abstracts, short contributions, comments, messages, and other contributions for the message section (i.e., President’s Message, In Memoriam) are collectively grouped as Miscellaneous contributions. Submissions are accepted year-round via the new online system. Every paper is reviewed by two reviewers. Some Miscellaneous contributions might only be reviewed by 1 reviewer.

We are using the new platform review module and will soon add its publishing module. The links to the new review module, and guidance documents (for creating an account, authors, submission format, editor and platform) will also be placed on the WMA website, journal page.

Dr. Thomas P. DeFelice
WMA Editor, 2024

UNDERSTANDING THE ECONOMICS OF CLOUD SEEDING PROJECTS

Sigmund Silber

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1.0 INTRODUCTION

Global warming and population growth are the largest contributing factors to the need to create more water. The impacts vary but typically are greater at lower latitudes (IPCC 2023). The general approach with cloud seeding is to assist clouds in converting the moisture in clouds to become snow (or in the tropics large raindrops) so that in both cases they are heavy enough to fall from the clouds to the ground (ASCE 42-23). Importantly, precipitation in general soon returns to the atmosphere so the water molecules are available to precipitate again and again. Cloud seeding speeds up the process slightly. Cloud seeding can be used for three different purposes: Precipitation enhancement, hail suppression, and fog dispersal. The discussion in this article would apply to all three purposes and most projects of any sort since it is general economic theory. But my focus in this article is on precipitation enhancement.

For a proposed cloud seeding project it is important to know whether or not it is economically justifiable and, if implemented, continues to be economically justified. We know that where conditions are appropriate, cloud seeding can increase the precipitation amount over a desired area. The reason for this is that natural precipitation processes are very inefficient. That is why precipitation occurs in many parts of the world that are many miles from the atmospheric moisture source. The atmosphere can hold a lot of water in its vapor state depending on air temperature but often needs coaxing to release this moisture or convert it to its liquid or solid state. Global Warming increases the ability of the atmosphere to hold moisture. In some cases, it increases the amount of coaxing required to produce precipitation as snow rather than rain. In some cases, rain is equal or more valuable than the water content of snow (SWE) and in some cases, rain is less valuable or even detrimental.

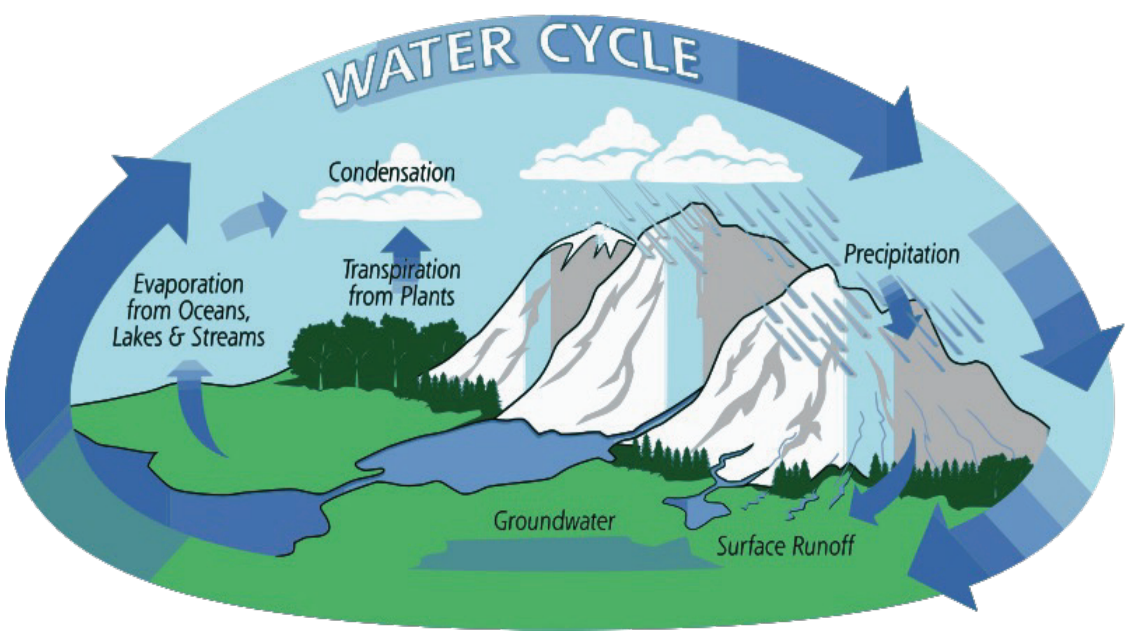

Fig. 1. A summary of the Water Cycle. Source: https://openclipart.org/detail/289930/water-cycle

2.0 HYDROLOGIC CYCLE: SOMETIMES CALLED THE WATER CYCLE

If I added New Mexico numbers to Figure 1 to help explain the concept, the most reliable number (estimated based on measurements) would be the 100 million acre-feet of precipitation in an average year. Some of that water recharges aquifers. About 2 million acre-feet enters the water supply (supplemented by some inflow from Colorado). Some water evaporates or sustains plant life (transpiration) in remote areas.

What is important is that other than aquifer recharge, all water quickly returns to the atmosphere. Working backwards using my estimates for New Mexico to have 100-million-acre feet of precipitation in an average year there probably are about 300 million acre-feet of water in clouds and that might mean that 1.5 to 2 billion acre-feet of moisture passes over New Mexico. Whatever the exact numbers are, there is plenty of moisture to work with.

It is important to remember that water is a compound that is almost impossible to destroy. States view the consumption of water in agriculture as a depletion of the state's water resource but evaporation and transpiration of plants in the process of photosynthesis returns the water to the atmosphere where it can precipitate and benefit others in the same state or other states or other nations. This can be repeated over and over again. Precipitation over oceans or water run-off into oceans makes that water unusable (other than, importantly for marine life) unless it is purified. However, the water is not destroyed and can be recovered and used (usually in arid areas such as Israel). Most of our precipitation comes from clouds that form over large bodies of water. So, it is best to view all of this as a cycle. Moisture evaporates from bodies of water or the ground or transpires from plants and enters the atmosphere. Under certain conditions moisture forms clouds. Again, under certain conditions, some of the moisture in clouds precipitates. Precipitation often provides value to people and the environment but mostly (groundwater is an exception that we do not cover in this article) rather quickly returns to the atmosphere to provide the moisture necessary to form more clouds for another round of precipitation.

3.0 USING CLOUD SEEDING TO INCREASE THE VELOCITY OF THE HYDROLOGIC/WATER CYCLE AND HOW THIS RELATES TO THE ECONOMICS OF CLOUD SEEDING

Cloud seeding can speed up the process compared to nature which means that individual water molecules end up providing benefits more times in a year. This process is not widely understood by the general public which sometimes misinterprets the process as robbing Peter to pay Paul. In reality, what happens is that Paul benefits when this might not have happened without cloud seeding. Then it may be someone other than Peter who next benefits from a particular water molecule. In a way, it is analogous to the money supply. For simplicity, consider a situation where printed currency is the only form of money. When the economy is good, a given unit of currency (for example a one-dollar bill) will pass through the hands of more people than when the economy is less good. So, increasing the velocity of money is often a good thing. Within narrow limits, we can increase the velocity of the hydrologic cycle and increase the contribution of water to society.

4.0 ECONOMIC ANALYSIS OF POTENTIAL AND OPERATIONAL CLOUD SEEDING PROJECTS

We know that with cloud seeding we can increase the velocity of the hydrologic cycle and increase the contribution of water to society, but some possible projects and existing projects are more desirable than others. Economics is the discipline where existing and potential projects are compared to prioritizing the application of human effort and capital.

Generally, projects that do not produce more value than their cost are non-economic. I will not address the exceptions to this rule because it devolves into a semantic issue of how one defines value.

But even if the approach produces more value than the cost you still must look at:

- Who benefits and
- Who pays

If the payor and beneficiary are different, there can be problems. In healthcare it is even more difficult because there is usually a third party involved i.e. the insurance company. That creates a very complicated situation which I addressed in a project done by the Diebold Group, Inc for the Robert Wood Johnson Foundation (1990-1994). There are some aspects of that three-way situation with cloud seeding also if government funding is involved.

There can be other factors which complicate the analysis. This is especially pertinent in the U.S. West and Plains States where most U.S. cloud seeding takes place. In most cases, the allocation of the water supply is based on the Priority Doctrine (PD). This means that with cloud seeding, the identity of the direct beneficiary of the additional water is often not known. If more water is available, it goes to those who otherwise would not receive water because their priority would not have been high enough. Priority is usually determined by who diverted and put the water to use first. That may not seem to be an optimal way to do things, but it tends to avoid violence since it is easier to determine who put the water to use first than to agree on which uses are better for society than other uses. There are also limited applications of the Riparian Doctrine where cloud seeding takes place in the United States, and it also can complicate economic analysis in a way that is similar to the Priority Doctrine.

Often there is an exception, namely that precipitation which falls on your land can be used by the landowner or the land owner's designee (typically a renter of the land) as long as the water does not leave the boundaries of the property. If it leaves the property, it typically enters the public water supply, and the Priority Doctrine takes over. However, the specific rules vary by state in the U.S.

A further complication is what are called interstate river compacts which are agreements among states concerning the distribution of the available water supply. The reason this is important concerning cloud seeding is the beneficiary may be in another state. Two important interstate river compacts are the Colorado River Compact and the Rio Grande River Compact. Both also have delivery requirements to Mexico. There are many other interstate river compacts. In general, each one has its own rules. When there is a potential violation of a river compact, the typical response is fallowing of land. Cloud seeding can reduce the amount of land that needs to be fallowed. Who fallows the land might be determined by the priority doctrine but often the taxpayer foots the bill to pay water-rights owners to forgo the use of water. This might not be fair to taxpayers and can create unintended consequences such as dust and erosion.

There are two major categories of beneficiaries:

A. A direct beneficiary who puts the additional water to beneficial use.

B. A governmental entity that is obligated to deliver water downstream for the benefit of other direct beneficiaries. This can be considered an indirect beneficiary or a facilitator.

Looking at things from a different perspective, the major beneficiaries of water are:

- Farmers
- Ranchers
- Municipalities, especially with regard to their need to deliver water to people and for other uses within a municipality (they could be considered an indirect beneficiary with the ultimate consumer being the direct beneficiary, but they profit from the availability of additional water)
- Ski resorts (they benefit from snow that falls from clouds or water to make snow)
- Hydroelectric facilities to generate electricity

- Commercial and industrial users who are not getting their water delivered to them by municipalities
- Recreation
- The environment

Some of the above consume the water and others simply use it and pass it on (hydroelectric and ski resorts). For those who from a legal perspective consume water, that water generally returns to the atmosphere or is treated and reused. So, our use of language in water administration (e.g. consume and deplete) can be somewhat inconsistent with science when it comes to water.

5.0 ECONOMIC IMPLICATIONS OF THE ABOVE

In some cases, the payor/funder of a cloud seeding project is also the direct beneficiary. That is the simple case since the payor can decide if the cost is worth the benefit.

In many cases, the payor of a cloud seeding project is an indirect beneficiary. That is often the case with the interstate river compacts and it is sometimes difficult to get projects funded that assist states in meeting their compact obligations.

The general rule is that cloud seeding is more easily funded when the beneficiaries recognize that they are benefiting from a cloud seeding project. The more direct it is the clearer it is. The more indirect it is the less clear it is. There are ways to deal with this problem but they usually require a high level of effort which may be beyond the ability of many cloud seeding operators and is not guaranteed to result in a contract so many potentially economic projects are never attempted or attempted only when sufficient local interest develops.

6.0 FURTHER DISCUSSION

The economics of cloud seeding are complicated. One way of looking at this is that cloud seeding often resembles infrastructure. When a road or bridge is built it usually is not clear exactly who will benefit. Generally, the consideration is whether or not the community or state or the U.S. will benefit. If funded with tax money (or borrowing which usually translates into property taxes) some will have paid for something that does not benefit them but others, and some will benefit many times more than their taxes.

In many cases, cloud seeding is like that. But in some cases, the direct beneficiary can be identified. Perhaps the best example of that would be ski resorts. They benefit from more snow falling from clouds thus having to make less snow. Hydroelectric in some cases is much like the ski resort example. The hydroelectric utility or the users of the generated electricity benefit and they can often recognize the value of cloud seeding to increase the generation of electricity. But on the Colorado River, it is often unclear who would be the beneficiary of more cloud seeding since there are so many different beneficiaries of there being more water in the river. A special case is when the delivery requirements of the interstate river compact are not being met, and the two alternatives are to find more water or use less water.

So, there is often a combination of private and public funding of cloud seeding. As a general rule, the greater the distance of the cloud seeding project from the beneficiaries the more difficult it is to have taxpayers or local government entities see the value to them of such a cloud seeding project.

6.1 <u>Secondary and Tertiary Beneficiaries</u>

So far, I have discussed the direct and indirect beneficiaries of cloud seeding. This is based on my knowledge of how cloud seeding projects should be and are usually evaluated in practice. A characteristic of direct and indirect benefits is the usual metric used is the cost of additional water resulting from an existing or proposed cloud seeding project.

Secondary and tertiary benefits are looked at differently. Cloud seeding does have secondary and tertiary impacts, but these are not generally considered because they are more difficult to estimate.

Some of these benefits result from the activity of the cloud seeding project to produce more water. Workers are hired and there are other purchases in the community to support the cloud seeding project. But the larger part of the secondary and tertiary benefits results from putting the additional water to use or avoiding the loss of economic activity from not making up for water deficiencies.

For large projects, the importance of secondary and tertiary benefits becomes increasingly important. But most cloud seeding projects can be justified based on the lower cost of the additional water as compared to other alternatives. I provide this discussion mostly because I think it will be used more often in the future.

IMPLAN or similar software can be utilized for that purpose. There are controversies about the validity of tools like IMPLAN which are based on secondary and tertiary impacts (Keynesian Economics) when an economy is near or close to full employment and the assumptions needed to use a tool like IMPLAN probably exceed the ability of most cloud seeding Operators except if a very large project is involved. But an understanding of the concept can be useful even when not fully utilized.

Secondary impacts include the economic activity of the suppliers to the cloud seeding project and the direct and indirect beneficiaries. Tertiary impacts include the benefits from the activity of all who supply the expanded economic activity of the direct and secondary beneficiaries. More water can increase economic activity or preserve existing economic activity. In many cases it can create or maintain a community where water is central to the existence of the community due to mining or industrial activity based on water availability.

7.0 REFERENCES

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ADDITIONAL RESOURCES:

Weather Modification Association, https://www.weathermod.org

North American Weather Modification Association map of current projects, http://www.nawmc.org

ASCE EWRI Weather Modification Standards and Guidance Manuals, https://ascelibrary.org/doi/book/10.1061/9780784414118

Information on the Author

Sigmund Silber has a Bachelor's degree in mathematics from Lehigh University (starting initially in their physics program) and a Master's degree in mathematics from NYU. He studied economics at the New School for Social Research in NYC but did not complete the PhD program. Years ago, he taught a graduate level Engineering Economics course at the Polytechnic Institute which is now part of NYU. Mr. Silber, is the President of S. Silber & Associates LLC and is also the President of the New Mexico Weather Modification Association and is a member of the ASCE EWRI Weather Modification Standards Committee.

THE ROLE ATMOSPHERIC WATER MANAGEMENT TECHNOLOGIES MIGHT PLAY IN WATER SECURITY SOLUTIONS*

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Parts of this paper were presented at the 2023 European Geophysical Union and 2023 WMA Annual Meeting, Westminster, CO

1.0 INTRODUCTION

Atmospheric water management professionals apply science and engineering principles to add water to a hydrodynamic ecosystem to help ensure its security and sustainability. The addition is accomplished by using cloud seeding technologies, while respecting and avoiding damage to public health, safety and the environment. Ensuring water security and sustainability requires implementing a multi-disciplinary solution 'now' and in the future, which some believe should include cloud seeding technologies (e.g., Wehbe et al. 2023). This study conceptually explored how and why cloud seeding technologies for precipitation enhancement might be a positive component within a water security and water sustainability solution. As noted in Keyes et al. (2016), WMO (2018), and ASCE (2023) for example, cloud seeding technologies have limits to their application. Water security/sustainability solutions are also very complex and have their unknowns (e.g., WMO 2018; UN 2019; WMO 2024). This paper includes a summary of atmospheric water management technologies, their applications to water security/sustainability and then a closing remark will follow.

2.0 ATMOSPHERIC WATER MANAGEMENT (CLOUD SEEDING) TECHNOLOGIES

Operational weather modification or cloud seeding activities have been conducted for at least seven (7) decades. These activities are scientifically designed and engineered for the purpose of positively affecting the earth's hydrologic cycle, particularly with respect to the precipitation process and can increase the precipitation above normal amounts (e.g., Orville et al. 2004; Garstang et al. 2005; French et al. 2018). Garstang et al. (2005) clarifies the operational and research viewpoints, i.e., long-term existence of cloud seeding, versus the lack of understanding of the physics of the precipitation process and human effects (e.g., DeFelice 2018) as reasons behind why the research community views cloud seeding as not effective. French et al. (2018) provide additional proof that cloud seeding technologies can be effective. Positively affecting the natural precipitation process might for example be needed to undo the negative impact(s) from natural and/or anthropogenic processes and their inadvertent effects that contribute to climate change. The limitations to their application, along with the environmental friendliness of these technologies are well documented (e.g., Keyes et al. 2016; WMA 2018; WMO 2018; ASCE 2023).

Cloud seeding activities effectively enhance or augment precipitation process efficiency with no significant, if any, negative environmental impacts compared to natural processes when implemented following a standard practice (e.g., ASCE 2023). The materials used to conduct cloud seeding are commonly silver iodide (AgI) containing ice nuclei for cold clouds and hygroscopic nuclei for warm clouds. The silver iodide molecule has been mistakenly associated with free silver ion, which causes silver toxicity. AgI does not cause silver toxicity because it does not dissociate into a free silver ion (e.g., Cooper and Jolly 1970; Howell 1977; Klein 1978; Dennis 1980; Hogstrand et al. 1996; Karen et al. 1999; Sanchez et al. 1999; Edwards et al. 2005; Stone 2006; Huggins 2009; WMA 2009; Cardno ENTRIX 2011; Fisher et al. 2016; WMA 2018).

Warm cloud seeding agents (e.g., calcium chloride or CaCl2, potassium chloride or KCl, NaCl) have been used during the last three (3) decades. Very few, if any, specific environmental toxicity study results have been published. The National Acid Precipitation Assessment Program (NAPAP) (e.g., NAPAP 2005) did obtain relevant wet chemistry components in precipitation and clouds and analyzed their impact on the environment and humans. The NAPAP plus the limited use of hygroscopic materials, and the lack of negative environmental reports suggest hygroscopic seeding would not likely be environmentally toxic. However, further studies are needed and should be conducted regularly before, during and after hygroscopic cloud seeding projects.

The implementation of the standard practice for precipitation enhancement (ASCE 2023) using cloud seeding technologies has built in mechanisms that help mitigate the potential for possible environmental issues from cloud seeding through adhering to standard practices, suspension criteria under hazardous conditions (e.g., snowpack depth, avalanche, severe weather), and a regulator's permit requirement (e.g., environmental impact). Hence, there is high confidence that cloud seeding technologies can support socio-economic, nature-based solutions to water security and sustainability.

3.0 APPLICATION TO SOLUTIONS CORRESPONDING TO WATER SECURITY AND SUSTAINABILITY

In 2018, 2.3 billion people were living in water stressed areas, while 3.6 billion people faced inadequate access to water at least one month per year (WMO 2024). WMO (2024) further notes that the number of people living in water stressed areas will grow to more than 5 billion by 2050. Water sustainability is about ensuring enough water for the future while water security is about having enough water now. The capacity of a population to safeguard sustainable access to adequate quantities and acceptable quality of water is commonly divided into four (4) functional focus areas or key dimensions:

i. Drinking water and human well-being

ii. Economic activities and development

iii. Ecosystems

iv. Water-related hazards and climate change

Each key dimension generally has governance, infrastructure, economic, societal and natural influences. The natural influences mainly encompass the atmospheric portion of the water cycle and its interface with the surface, which are significant parts of the 'Water-related hazards and climate change' and 'Ecosystems' dimensions but also effect the other dimensions. Desalination, water system management, and education are the predominant focus of water management tied to security programs (e.g., UN 2019). Obtaining water security and its sustainability requires collaboration across the focus areas, disciplines, communities and geo-political borders. Its solution then necessitates a multi-disciplined approach. Given precipitation is the only fresh input to the water system, there should be mention or at least consideration of adding precipitation to the system when it comes to water security solutions.

4.0 CLOUD SEEDING TO SUPPORT A WATER SECURITY AND SUSTAINABILITY SOLUTION OR PROGRAM

Cloud seeding technologies may be useful parts of "Ecosystem" and "Water related hazards and climate change" cross sector focal area components to water security and sustainability solutions. They are designed to add precipitation to a water system supply. The operational strategy for applying established current cloud seeding technologies at a local level, might conceivably differ from their application to increase precipitation process efficiency at a water security level, depending on the; (i) root cause of the inefficiency, (ii) complexities of the scales of motion and (iii) details of the land cover/land use (LC/LU) to atmosphere interface and nuclei-cloud interactions involved in the cloud system. Root cause examples might include air pollution or high dust loading.

A possible initial high-level strategy might use cloud seeding to:

- Support extending ecosystem surface land cover/land use coverage
- Contribute to drinking water, and Economic development
- Minimize the climate extremes to sustain and enhance ecosystem efficacy.

The 'support' in the first point refers to the addition of rainwater to sustain the life cycle of the vegetation for all land uses. The second point is primarily related to economic development, i.e., enhancing seasonal outdoor recreation, agriculture, and crops. Cloud seeding could also help reduce the need to desalinate water for example.

Reconsidering how to implement a seeding program as part of a water security/sustainability solution is conceptualized in Table 1.

Conceptually, one would need to improve or reconfigure seeding strategies, cloud seeding technologies and models, observations, and ultimately decision support tools. For example, the implementation of operations might need to be annual and repeated for decades, in contrast to the current typical seasonal approach. The LC/LU extended ecosystem area would become and

Table 1. A conceptual comparison of standard practice for precipitation enhancement projects (ASCE 2023) to its use as part of a water security and sustainability solution.

	Existing Precipitation Enhancement Projects	**Water Security/Sustainability Projects**
Area	Local/regional (catchment area, county or multiple counties, full province or state)	Regional/transnational (multiple regions, entire country, multiple countries)
Duration	Seasonal, subject to funding (monthly)	Annual, long term (decades)
Seeding Target	Rural primarily Static per project year	Rutal and urban, Dynamic (evolves per project year and location)
Precipitation Type	Rain, Snow, Hail	Rain, Snow
Hail Suppression	For crop damage mitigation	Not applicable for water security and sustenance
Evaluation	Target/Control, e.g., ASCE (2023) Single discipline measurement (e.g., Precipitation amount)	Target/Control, e.g., ASCE (2023) transnational/cross border Multi-discipline measurements (e.g., precipitation amount, LC/LU, sociological, economic)
Funding	Private, commercial, local government	National government(s), UN/WMO funding

remain the target area. The target area is anticipated to be non-static contrary to that in typical cloud seeding projects. The operational strategy, societal incentives, public outreach, and evaluation components will all need to be reconfigured to the larger scale necessary to meet water security and sustainability goals.

The cloud seeding operations:

- will be focused on precipitation enhancement (ASCE 2023),
- may become daily throughout the year for decades,
- will be more robust and scalable regarding societal incentives and public outreach.

There may also be a need to facilitate a more dynamic evaluation framework (including monitoring). The environmental impact, science/engineering R&D, and the supporting mitigation plans (e.g., relevant environmental changes and their impacts) may also be different.

5.0 CLOSING REMARKS

Cloud seeding is a proven, viable and cost-effective technology that will enhance precipitation and is unlikely to harm the environment. It could possibly be a useful part of an implementation plan for water security/sustainability. Further work is required to evolve the standard practice framework to effectively support this application.

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TEXAS CLOUD SEEDING EXPERIMENTS USING ELECTRICALLY CHARGED DROPLETS

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ABSTRACT

Research operations, using electrostatically charged water droplets as a seeding agent, were conducted in convective clouds over West Texas as an exploratory experiment in 2017. Research continued later in its confirmatory phase through 2022. The initial research flights were conducted using an Air Tractor 402B provided by the USDA, and later both a Piper Comanche and 502B were equipped to extend those operations. For the assessments of possible impacts, radar data and TITAN software were used, following the same protocols established for the evaluations of long-running operational cloud-seeding programs in Texas. A total of 18 small and isolated seeded clouds were compared with similar control (unseeded) cases provided by the TITAN software. Such a comparison indicated significant increases in lifetime, area, precipitation flux, and precipitation mass among other variables of interest, and the average increases appeared to be larger than those obtained with glaciogenic (silver iodide) flares used in the legacy rain-enhancement projects in Texas (1996-2023). In this paper, we summarize the approach taken in the research and results from the analysis of data, both of which led the U. S. Department of Agriculture to request a U. S. patent which has since been issued.

1.0 INTRODUCTION: PHYSICAL FOUNDATIONS

1.1 The use of water droplets for weather modification purposes preceded the experiments carried out by I. Langmuir, V.J. Schaefer, and B. Vonnegut using glaciogenic agents (dry ice and silver iodide) to target supercooled water within the clouds (late 1940's). In 1938, H.G. Houghton and W.H. Bradford reported the successful dissipation of warm fogs using sprays of hygroscopic solutions, particularly those of calcium chloride. Their experiments were done at the M.I.T. field station in South Dartmouth, Massachusetts, and they demonstrated that fog droplets could be removed by using large electrically charged particles (water drops or sand). They found the most difficult challenge to be producing large particles with sufficiently uniform size distribution (Houghton and Radford, 1938).

1.2 In the 1950s, the Commonwealth Scientific and Industrial Research Organization (CSIRO, Australia) implemented cloud seeding operations using water droplets. In 1952, eleven experiments were done in which small water droplets of median radius 25 microns were sprayed at a rate of about 1.9 liters per second (~30 gallons per minute) at some 300 meters above the cloud base. Most of the seeded clouds (ten of eleven cases, ~91%) were reported to have developed rain signatures, whereas nearby unseeded clouds did not. In four cases, when the cloud thickness was larger than 1,500 meters, the modification signal was vigorous (Mason, 1975). Similar experiments were conducted in the Caribbean by Wallace E. Howell with similarly promising results, but the extension of the technique to large-scale applications was then considered extremely costly and in need of more research (Fenn and Weickmann, 1959; see also

Mason, ibid, and Cotton, 1982). It is important to emphasize that those experiments were made before a clear explanation of the collision-coalescence mechanism was known.

1.3 The first model demonstrating rain production as a consequence of a chain reaction was presented by Irving Langmuir (1948) when he wrote:

"…These droplets, under favorable conditions, would grow to such a size that they

will break up into two or more large drops and also produce a relatively large number

of small droplets which, however, would be larger than the cloud droplets."

It was a move away from the original work of Houghton and Radford at MIT and from the three-phase process of precipitation formation (Bergeron-Findeisen). In the mind of Langmuir, the target may be not only fogs but clouds aloft, with or without supercooled water.

In the early 1950s, F. H. Ludlam (1951) followed Langmuir's ideas by modeling how a collector droplet will move in an updraft, growing at the expenses of smaller droplets. Ludlam calculated the minimum vertical extent in a cloud necessary for the formation of showers by accretion: the final raindrop radius as a function of updraft speed. Ludlam's model considers a large droplet (a collector) entering the base of a cloud and being carried upward by an updraft of velocity V. Because the terminal velocity is a function of the droplet size, the raindrop radius becomes a function of the updraft. Further simplifications lead to the following:

$$H = \int_{h_0}^{h_{top}} dz = \frac{4\rho}{\varepsilon w} \int_{r_1}^{r_{top}} \frac{U - V_T(r)}{V_T(r)} dr; \Delta t = \frac{4\rho}{\varepsilon w} \int_{r_1}^{r_{final}} \frac{1}{V_T(r)} dr$$

By assuming an accretion efficiency ε = 0.85, Ludlam found a minimum height *H* was necessary for droplets to grow to rain-embryo sizes. Higher values of efficiencies can also be assumed.

1.4 In the 1970s, a sound scientific explanation was reached about how cloud droplets grow up to precipitation sizes by the collision-coalescence mechanism. Succinctly stated, droplet growth occurs from both small and large droplets, a consequence of large droplets having larger fall velocities, allowing them to collide and collect small droplets (the minority of large droplets, the collectors, grow at the expense of the small droplets, the collected). The whole process is described by two coefficients, the collision efficiency $E_{collision}$ and the coalescence efficiency $E_{coalescence}$, (Bartlett, 1972; Klett and Davis, 1973; Lin and Lee, 1975; Schlamp et al. 1976). The mechanism works as follows: (1) collision efficiency is negligible unless the collectors have radii of at least 20 microns; (2) for collected droplets with radii of about 10 microns and collectors with 40-micron radii or larger, the collision efficiencies approach unity; and (3) for larger collector radii, the collision efficiency may exceed unity by wake capture.

1.5 Uncertainties and caveats about the previous statements can be attributed to turbulence, the amount of available water vapor, the temperature field, and particular electrical conditions. Multiple observations show more rapid droplet growth takes place under enhanced turbulence, whereas the presence of electric fields enhances coalescence efficiency due to the presence of induced dipoles in these droplets. Other, more detailed observations suggest that adding collector droplets of proper size (radii ~ 40 microns) with electric charges of about 50 picocoulombs may trigger the collision-coalescence mechanism. Modeling has shown that the collision efficiency between charged and neutral droplets and/or charges of opposite sign can be drastically enhanced even if the electric charges are well below the Rayleigh limit of disruption (Khain et al. 2004; visit also Pruppacher and Klett, 1997). Thus, it can be hypothesized that operational seeding of vigorous convective clouds in a continental environment, using electrically charged droplets with radii of about 40 microns, should enhance the collision-coalescence mechanism in the seeded clouds, leading to noticeable increases in precipitation.

2.0 CONCEPTUAL MODEL AND ITS OPERATIONAL IMPLEMENTATION

2.1 The conceptual model was developed as input was gathered from the earliest experimental flights. It is the main pillar for future actions and should be modified if needed. The sequence of events outlined by the model follows:

CM1: a continental cloud with a quasi-uniform droplet size distribution (high colloidal stability) is seeded at its base within the inflow with 40-micron radius electrically charged water droplets (collectors).

CM2: the collectors grow at the expense of the background smaller droplets by collision and coalescence. With time, these collectors in the updraft should become precipitation drops. The minimum depth needed for a collector to reach precipitation sizes is roughly proportional to the updraft velocity.

CM3: base seeding operations with electrically charged collectors may be extended to mesoscale convective systems and stratiform clouds. For layered clouds, top seeding might be used.

2.2 An agricultural aircraft was equipped with a spraying system that was outfitted with a series of spray nozzles. This produced an atomized spray at proprietary and tested droplet size and distributions. The spray nozzles were surrounded by an electrically charged stainless steel electrode designed to induce a polar opposite charge to the fluid sprayed from the nozzle, as seen in Figure 1 (Martin et al. 2022). In this study, only water was used as the seeding agent. The equipped aircraft took off and received direction to a candidate cloud with measurable updraft by a licensed meteorologist. The pilot then flew 500 feet

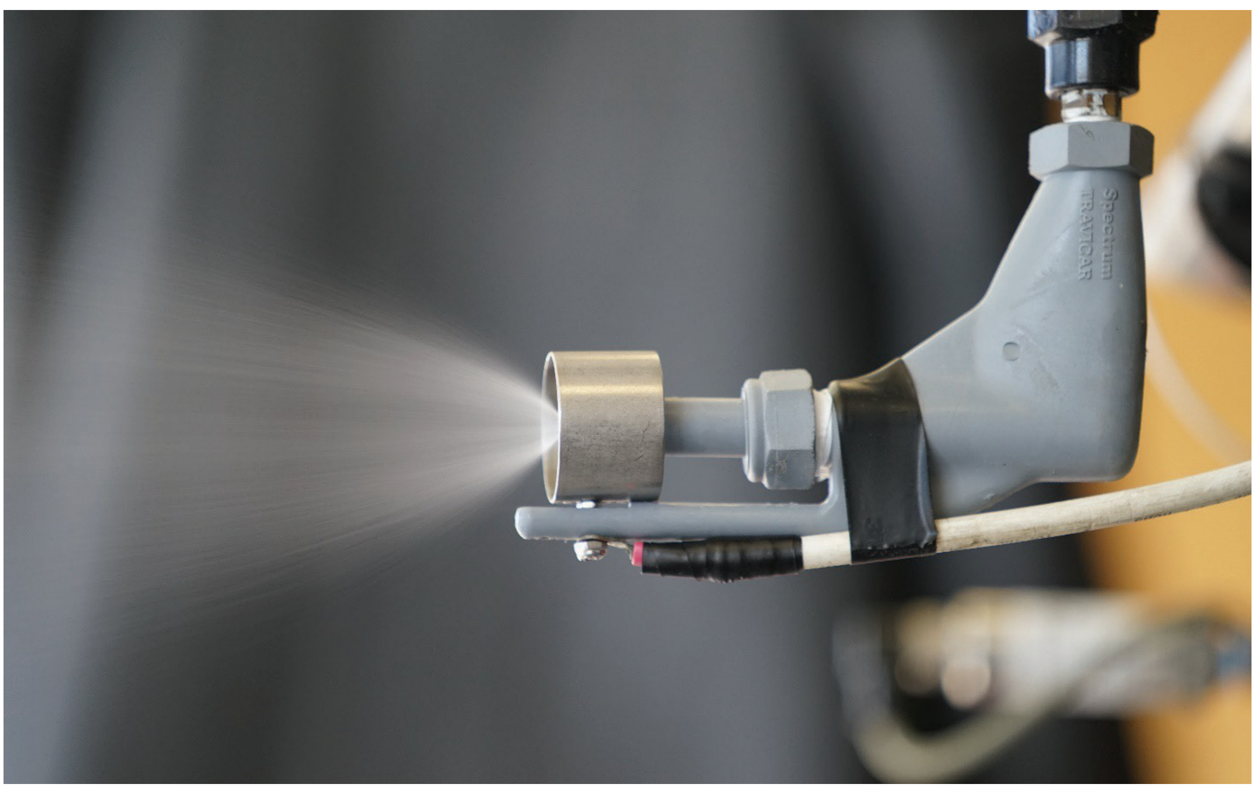

Fig. 1. An electrostatic nozzle encased within the electrode to induce an electrostatic charge on the spray cloud emitted from the nozzle tip.

Fig. 2. (Right) USDA-ARS Air Tractor 402b used in the 2017 Texas pilot project and (left) a close-up view of the nozzles.

below the target cloud and turned on the spraying system so that charged pressurized water was sprayed out of the nozzle when specific inflows were found using the aircrafts vertical speed indicator. The inflow then carried the electrically charged droplets up into the cloud to invigorate the droplet growth through collision and coalescence of the warm rain process.

2.3 Research operations were directed from the West Texas Weather Modification Association Office in San Angelo, Texas. The Thunderstorm Identification, Tracking, Analysis and Nowcasting (TITAN) software program was used for operational decision-making and later for the assessments (Bates and Ruiz-Columbie, 2002). As mentioned before, these research operations followed the same protocol already established for weather modification operations in the local project. The research study using electrically charged droplets began in June 2017.

2.4 Importantly, to preserve the integrity of the local operational program, the spray seeding approach embraced the same operational focus (non-randomized seeding), although some random-like criterium took place when considering where to locate the seeding aircraft. In short, locations of the seeding aircraft were decided by available resources and seeding operations using flares and water droplets occurred generally on opposite sides of the target area. This design enabled comparisons between the two types of seeding.

3.0 RESULTS AND ASSESSMENTS

3.1 Comparisons between clouds seeded with electrically charged droplets and similar control (unseeded) cases, as well as quasi-synchronous seeded clouds using glaciogenic flares and correspondingly similar control (unseeded) clouds, were made to determine possible seeding effects. In both comparisons, the control cases were determined using TITAN software (TrackMatch.test utility). The results are presented here in the same format as used for operational assessments in Texas. The two tables are provided.

3.1 Conclusions:

First: In terms of precipitation production, seeding operations with electrically charged water seemed to be more efficient (208 % versus 90 %) using 18 data samples. However, other storm radar variables appeared to be more impacted by the flare seeding using 24 sample pairs. Note that the increase in volume above 6 km, where supercooled water is observed, is 130% versus 107%, a possible indication that although electrically charged water droplets can reach supercooled levels depending on the updraft intensity, they primarily affected the warm region of a storm.

TABLE 1. Small-seeded clouds with electrostatically charged droplets compared to controls clouds (18 couples).

Variable	Charged Sample	Unseeded Sample	Simple Ratio	Increase (%)
Lifetime	55 min	40 min	1.38	38 (31)
Area	72.3 km^2	40.7 km^2	1.78	78 (62)
Volume	267.2 km^3	129.6 km^3	2.06	106 (84)
Top Height	9.1 km	8.5 km	1.07	7 (4)
Max dBz	53.2	4.2	1.06	6 (3)
Top Height of Max dBz	4.1 km	4.2 km	0.98	-2 (-3)
Volume Above 6km	83.5 km^3	38.3 km^3	2.18	118 (107)
Precip. Flux	524.2 m^3/s	281.3 m^3/s	1.86	86 (116)
Precip. Mass	2078.9 kton	699.8 kton	2.97	197 (208)
Cloud Mass	187 kton	82.7 kton	2.26	126 (126)
N	11.1	8.5	1.31	31 (35)

Average timing: 0.7. Average seeding duration: 9.3 minutes. Average Dose: 23.5 gallons of Water. Notice the increase in precipitation mass of 208%.

TABLE 2. Small-seeded clouds with electrostatically charged droplets compared to dual seeded clouds (glaciogenic and hygroscopic, 24 samples).

Variable	Dual Sample	Unseeded Sample	Simple Ratio	Increase (%)
Lifetime	65 min	40 min	1.63	63 (48)
Area	73.6 km^2	55.4 km^2	1.33	33 (24)
Volume	247.6 km^3	153.4 km^3	1.61	61 (38)
Top Height	9.0 km	8.3 km	1.07	7 (4)
Max dBz	53.3	50.1	1.06	6 (3)
Top Height of Max dBz	4.1 km	4.2 km	0.95	-5 (-2)
Volume Above 6km	188.5 km^3	60.3 km^3	3.13	213 (130)
Precip. Flux	534.5 m^3/s	295.8 m^3/s	1.81	81 (54)
Precip. Mass	176.8 kton	949.7 kton	2.41	141 (90)
Cloud Mass	176.8 kton	86.7 kton	2.05	105 (27)
N	13.0	11.0	1.18	18/51

Average timing: 0.88. Average seeding duration: 9.2 minutes. Average Dose: 40 in/L (180 AgI flares, 3 hygroscopic flares (24 samples). Notice the increase in precipitation mass of 90%.

Second: The cost of operations may also be a consideration since current estimations indicate that using water droplets as a seeding agent appears to be nearly seven times more expensive than using flares. Additional considerations about environmental impacts may influence future actions.

Third: Due to limited resources, the actions herein described were done in an operational-oriented manner. Gathering detailed data describing microphysical changes in seeded and control cases should be an objective of future experiments to provide insight into how various seeding techniques impact the evolution, and productivity, of storms.

Fourth: The USDA, which conducts research for technology transfer, was confident enough in the results to request a patent in the technology which was approved as US 11,116,150 and pending continuation-in-part application 17/387,348 both entitled "Aerial Electrostatic System for Weather Modification."

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SOME COMMENTS ON WEATHER MODIFICATION REPORTING ACT REQUEST FOR INFORMATION (NOAA-OAR-2024-0091)

T.P. DeFelice

These comments are Tom DeFelice's opinion based on his academic, professional and non-professional experiences. They do not necessarily reflect those of any person he knows or has known, nor his current or former employers, organizations or other entities

1.0 INTRODUCTION

The National Oceanic and Atmospheric Organization (NOAA) Oceanic and Atmospheric Research (OAR) was tasked with soliciting public comment on a petition for rulemaking to amend NOAA's reporting regulations under the Weather Modification Reporting Act 15 CFR part 908 (https://www.ecfr.gov/current/title-15/part-908). NOAA was particularly interested in:

1. How NOAA should update 15 CFR part 908 (https://www.ecfr.gov/current/title-15/part-908) reporting requirements to account for solar radiation modification experiments.
2. What reporting requirements NOAA should include regarding potential and/or measured environmental impacts of weather modification experiments given the state of the science and current detection capabilities.
3. The spatial scale of weather modification experiments and their intended effects for which NOAA should request in submitted reports.
4. Whether, under existing statutory authorities, NOAA should pursue a broader regulatory strategy for solar radiation modification research and experimentation.

NOAA indicated it would consider public comments received to determine whether to proceed with the petition's requested revisions. NOAA will publish an updated 15 CFR part 908 in the Federal Register.

2.0 DISCUSSION

Some thoughts related to the requested information items are highlighted.

1. How NOAA should update 15 CFR part 908 reporting requirements to account for solar radiation modification experiments

NOAA should not add reporting requirements for solar radiation modification experiments to 15 CFR part 908. Solar Radiation Modification or modification of incoming solar radiation (insolation) has very little if anything to do with cloud seeding or weather modification.

2. What reporting requirements NOAA should include regarding potential and/or measured environmental impacts of weather modification experiments given the state of the science and current detection capabilities.

Current reporting activities in the US and abroad must continue. The reporting process needs to be standardized. Some operational weather modification companies have expressed their concerns and provided relevant inputs. In addition to current reporting requirements, weather modification operations and research activity reporting requirements must at least include:

- An Environmental Impact Assessment and report.
- Target area size and shape, Operational Area (if not already reported; See below)
- Seeding agent used, how (i.e., Flare, solution via ground or airborne including UAS/UGV)
- Seeding Mode (airborne, ground), generator/flare type and numbers used.
- Seeding agent components in order of high to low or trace concentration including "filler(s)".

- Have a demonstrated active Public Information/ Outreach Plan before project starts.

- Seeding suspension criteria plan. The reporting must include times when criteria were not met, met, or were exceeded during operations, experiments etc., explain why, if seeding stopped and if stopped seeding when.

- If uncrewed systems (e.g., UAS/UGV) were used; add demonstrated evidence that FAA/ DOT regulations were followed throughout.

- A consistent mechanism to ensure reporting is completed and all contractors are compliant.

- Request observation types and area covered (e.g., Meteorologic, soil, hydrologic, land cover/ land use, soil moisture/temp. profiles and network name(s) or site specific for each project).

3. The spatial scale of weather modification experiments and their intended effects for which NOAA should request in submitted reports.

- The weather modification project spatial scale is the area covered by the target area, and the operations area. One might consider adding the area covered by possible downwind effects (DeFelice et al. 2014).

- The seeding material dispersal via aircraft is applied on sub-cloud scales and the seeding material dispersal scale via ground generators/flare trees is applied on sub-cloud to area scales.

4. Whether, under existing statutory authorities, NOAA should pursue a broader regulatory strategy for solar radiation modification research and experimentation.

I do think Solar Radiation Modification and geo-engineering or like technique research and development should be attached to a new statutory authority, or at least a new Part under Title 15. Solar radiation modification activity or geoengineering and other like techniques, including those I first read about in Hess (1974), do not belong under Weather Modification or cloud seeding.

I do see the need to clarify what Solar Radiation Modification is and what its reporting requirements should be. But not at the expense of weather modification.

- Solar Radiation Modification reporting could proactively avoid a global scale catastrophic event, i.e., ‘nuclear winter’ (e.g., https://en.wikipedia.org/wiki/Nuclear_winter)

- Cloud seeding technologies do not modify solar radiation, they do enhance the efficiency of our hydrologic cycle.

- Reporting could yield expanded salient information to assess the potential impacts and risks of Solar Radiation Modification activities.

- Assessing the impacts and risks of Solar Radiation Modification will:
    * Clarify what Solar Radiation Modification is.
    * Establish a proactive framework to guide the application of Solar Radiation Modification or similar techniques (i.e., geoengineering).

The Weather Modification Reporting Act 15 CFR part 908 (https://www.ecfr.gov/current/title-15/subtitle-B/chapter-IX/subchapter-A/part-908) was updated as of December 26, 2024 to include reporting Solar radiation intensity modification. Apparently, they feel geoengineering techniques such as modifying the solar radiation intensity are weather modification techniques if conducted as weather modification activity, and shall be subject to reporting, along with reporting modifying the characteristics of land or water surfaces by dusting or treating with powders, liquid sprays, dyes, or other materials; releasing electrically charged or radioactive particles, or ions, into the atmosphere; Applying shock waves, sonic energy sources, or other explosive or acoustic sources to the atmosphere; using lasers or other sources of electromagnetic radiation, and solar radiation modification activities are not seen as being conducted as a weather modification activity. Hence, they do not need to be reported at all, despite their ability to threaten national security. Solar Radiation Modification and like techniques and those named in this paragraph are not weather modification techniques. Perhaps this may change after,

(A) focused multi-disciplinary R&D (e.g., physical, chemical, biological, geologic, sociologic, economic) on developing/identifying their theoretical basis.

(B) mapping theory (A) to all atmospheric phenomena motion or time scale(s)

(C) accounting for the interaction between where the technique is applied and its surroundings

(D) reaffirming results in (B) and (C) and then employing a benefit-to-cost analysis.

3.0 CONCLUDING REMARKS

The Weather Modification Reporting Act 15 CFR part 908 (www.ecfr.gov/current/title-15/subtitle-B/chapter-IX/subchapter-A/part-908) was updated as of December 26, 2024 to include reporting of solar radiation intensity modification activities. Apparently, releasing electrically charged or radioactive particles, or applying shock waves, sonic energy sources, other explosive or acoustic sources, or using lasers or other sources of electromagnetic radiation to or in the atmospheric are not considered reportable. Those implementing said activities would not see such as weather modification activities. NOAA OAR should have recommended a new “Part” of Title 15 for solar radiation modification and the said geo-engineering techniques.

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