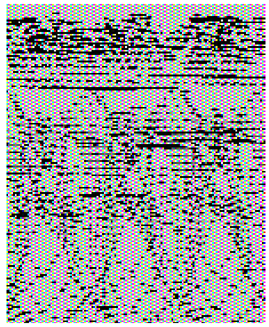

Benign Weather Modification

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Contents

Abstract

Weather modification is a technology once embraced by the United States (US) military as a tool to help both wartime and peacetime missions. However, interest in the ability to modify weather has waned over recent years and is now nearly nonexistent.

This study examines one aspect of weather modification, benign weather modification (BWM), for possible use in assisting military operations. After briefly reviewing the history and science of weather modification, this thesis bounds the aspects of weather modification being addressed. It then describes barriers to BWM, showing how they affect current weather modification policy in the military. Examples are shown of current civilian BWM techniques, their possible use by the military, and some military-unique needs for weather modification.

After examining current weather modification and projected future BWM technology, the author concludes that military BWM use deserves another look. Increased reliance on precision guided munitions makes BWM a possible new tool in ensuring accurate targeting with minimal collateral damage. In addition, BWM offers the war planner a means to dictate battle space elements at a critical point in a conflict. At a minimum, the US military should conduct a more in-depth review of weather modification to see if technological advances offer opportunities for more "bang for the buck."

About the Author

Maj Barry B. Coble was commissioned in 1981 through the Reserve Officer Training Corps at North Carolina State University. His first assignment was as an environmental simulations analyst at the USAF Environmental Technical Applications Center at Scott Air Force Base (AFB), Illinois. From there he went to Fort Bragg, North Carolina, as officer in charge (OIC) of 7th Special Forces Special Operations Weather Team and assistant OIC of the XVIII Airborne Corps Weather Team. After completing an Air Force Institute of Technology assignment, he returned to Scott AFB and worked in the Special Projects Directorate at Headquarters Air Weather Service. He then went to Ramstein Air Base, Germany, where he served as commander, Detachment 2, 31st Weather Squadron and as the technical operations officer at the 86th Weather Squadron. Major Coble has completed Squadron Officer School and Air Command and Staff College in residence. He has a bachelor's degree in meteorology from North Carolina State University and a master's degree in meteorology from Utah State University. In July 1996 Major Coble was assigned to Headquarters USAF as chief, Weather and Navigation Systems Requirements. He is a 1996 graduate of the School of Advanced Airpower Studies.

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I would be remiss if I did not express my heartfelt love and appreciation to my wife, Andrea, and my daughters, Misha and Piper. Their patience while I locked myself in my office on a nightly basis working on this study was greatly appreciated. Now I can go back to reading Dr. Seuss' books to you on a more regular basis, kids.

Chapter 1

Introduction

Everybody talks about the weather, but nobody does anything about it.

—Mark Twain

On 30 August 1995 a French Mirage 2000N carrying two crew members was shot down over Bosnia during Operation Deliberate Force. Two parachutes were spotted descending to earth, leading to the planning for a rescue attempt. The first combat search and rescue (CSAR) attempt, scheduled for 6 September 1995, was canceled due to unsatisfactory launch site weather for the participating aircraft. A second CSAR mission was then scheduled for 7 September 1995.

The second CSAR mission consisted of four helicopters and four variants of the C-130. Providing protection and close air support were 10 additional aircraft. All aircraft took off with no problems, and the mission was a smooth one until arrival of the CSAR package at the search area. There the aircraft encountered an unanticipated condition, fog. Fog was covering the valley where they expected to locate the crewmen. In all 18 aircraft had flown that night, only to be thwarted from completing their mission by a fog bank. At the end of September the Bosnian Serb Army told the world that they held the crew as prisoners, having captured them soon after they ejected over their territory. Their release came later.[1]

Weather and War—the two concepts are closely linked. Warriors throughout the ages have used weather to their advantage, and some have suffered from its effects on the outcome of battles. The timing of the Normandy invasion on D day, 6 June 1944, was dictated by a favorable weather forecast. While the Allied weather forecasters got it right, the German forecasters felt the weather would prohibit the successful crossing of the English Channel. This forecast contributed to the unsuspecting mood of the German military on that particular day. During the same war but in a different theater, the Japanese used the weather to conceal their approach to the Hawaiian Islands, enhancing their surprise attack on Pearl Harbor. There are numerous examples of situations where weather played the critical role in the outcome of war.

Historically the military adapts to the weather. What if military forces could shape the weather to enhance operations, hinder or prevent enemy operations, or both? Such is the promise of weather modification and its role in support of the military.

This thesis determines whether the military should revisit using weather modification for enhancing military operations. Weather modification is an area of operations that the military has tried, and because of a variety of reasons, has stopped conducting. I reexamine this decision by first looking at current weather modification science and what the future holds for the weather modification field over the next 10 years. A detailed look at weather modification limitations follows, with the idea of examining certain factors that retard or restrict military use of weather modification. The second portion analyzes civilian applications of weather modification which can be applied to military uses. It also looks at those weather modification applications which are/which appear suitable only for military operations. The recommendation and conclusion section proposes ways in which the military can, potentially, exploit any benefits of weather modification.

Limits of This Study

The idea of weather modification conjures up many different images. As a result, bounding this study will let the reader know exactly the meaning of weather modification in this context. United Nations (UN) treaties prohibit using weather modification to kill or maim people. Modifying weather to cause injury or death is outlawed. For instance, causing lightning to strike exposed enemy infantry is illegal. Therefore, discussion about deadly or hostile weather modification is beyond the scope of this work. Instead, I focus on weather modification aimed at suppressing existing weather or enhancing the effects of weather without causing direct physical harm to people. This type of weather modification is called benign weather modification (BWM). Any harm caused by BWM is strictly a secondary effect. For military operations, BWM is a way to enhance friendly actions or impede enemy actions.

The general notion of weather modification tends to create a negative response in many circles. It is pertinent to delineate the different types of weather modification capabilities and to discuss those that fall within the limits of the study. Further discussion concerning the "barriers" to weather modification efforts, why they exist, and why they need not apply to BWM takes place in chapter 3.

This study only examines the current state of the field and those advances expected within the next 10 years. While this may exclude some interesting and exotic forms of weather modification, what is most important at this stage is a good first step towards understanding possible military uses of BWM. This thesis mentions other BWM techniques that may aid future military operations. For the most part, however, the focus is on existing BWM techniques developed for civilian purposes. It seems likely that the transition of these techniques to military applications represents the most inexpensive option for military BWM, something quite desirable given current constraints in defense spending.

Why Study Weather Modification?

The history of weather modification by the military is checkered, to say the least. Initial interest by the United States (US) Department of Defense (DOD) goes back to the late 1940s, when the US Army Signal Corps contracted to provide support for Project Cirrus. This project was the first scientific effort to seed clouds in order to make rain. Shortly after the project began, the Office of Naval Research and the Air Force joined the research team and provided additional support to the project.[2]

During the 1950s and early 1960s, military interest in weather modification was limited. With the onset of the Vietnam War, operational interest in modifying weather to support combat operations increased, ultimately leading to a multiservice effort called Project Popeye. Its goal was to flood supply routes used by the North Vietnamese into South Vietnam by seeding clouds in the area. When this effort was exposed, however, the military endured tremendous pressure and criticism, especially from Congress. Within five years of the negative publicity, US military weather modification research had ceased, and operational use of BWM gradually declined. For instance, three Air Force bases had installed cold fog clearing equipment by the early 1970s. Currently the only cold fog clearing system that exists in the USAF is located at Fairchild Air Force Base, Washington, and it is used very sparingly.[3]

DOD funding for weather modification research peaked at $2.8 million in 1977. Funding was eliminated in 1979. Since then there has been no active research effort into weather modification by DOD. The Air Force spends no money on research, and there is no effort to monitor civilian research, applications, and advancements. The Army's program, "Owning the Weather for the Battlefield," deals only with incorporating weather information into the digitized battlefield of the future. Efforts to modify the weather for battle are not being pursued.[4]

Many countries throughout the world practice weather modification. The Russians have long been interested in using weather modification as a way to control hail.[5] The Chinese recognize the value of weather modification and believe, incorrectly, that the US military continues to use weather as a weapon.[6] However, there is little available evidence showing active efforts by other countries to use weather modification for military use.

The US military, especially the Air Force, is considered the preeminent world leader in technology and its applications in the battle space. Since the late 1970s, the Air Force has "backed away" from pursuing weather modification technology even though the scientific understanding and the technological capability have evolved, albeit slowly, over time. It is a well-known fact that weather affects the battle space, contributing to the "fog of war." New developments in the field of weather modification may help eliminate some of this "fog" and turn weather into a force multiplier.

Glossary of Weather Modification Terms

Weather modification is a scientific field with its own language and terms. The American Meteorological Society, the leading professional society of meteorologists, defines the term *weather modification* as "the intentional or inadvertent alteration of weather by human agency." A similar term, *weather control*, is defined as "weather modification, with the implication that modification effort is purposefully applied and its consequences predictable."[7]

The Joint Chiefs of Staff (JCS) have a definition of environmental modification. Although not explicitly defined, weather modification can be viewed as a specialized category under the more general environmental modification definition: "Environmental Modification . . . refers to changing (through the deliberate manipulation of natural processes) the dynamics, composition, or structure of the earth, including . . . [the] atmosphere."[8]

A mix of the two definitions is more appropriate for this study. Weather modification refers to the intentional enhancement or suppression of the current weather conditions over a given area by human agency. Inadvertent weather modification, which refers to the accidental alteration of weather via pollution or other human activities, is not addressed. This study does not use the term *weather control*. Since the natural weather producing processes associated with the earth-atmosphere system are nonlinear and dependent on feedback mechanisms, predictable consequences, as implied by the word *control*, are not a surety.

There are two basic types of weather modification: hostile and benign. Hostile weather modification is the use of weather as a weapon to harm people. Benign weather modification refers to enhancing or suppressing weather effects to benefit the modifier without directly harming others. BWM is also environmentally safe and, most important, not indiscriminate. These two concepts are often confused, as the term *weather modification* seems to carry with it the hostile connotation. Unfortunately, rejecting all weather modification may cause the overlooking of possible BWM benefits. This discussion deals with the benign aspect. A JCS directive prohibits using weather to harm people.[9]

The most well-known type of BWM is cloud seeding. It refers to any process of injecting a substance into a cloud for the purpose of influencing the cloud's subsequent development. A cloud seeding agent is any variety of substances dispensed for the purposes of cloud seeding. These substances include silver iodide, dry ice (frozen carbon dioxide), calcium chloride, salt, or carbon black to name a few.[10] Cloud seeding is one of the main areas of practical weather modification and is used to enhance or retard precipitation development as well as to increase or decrease cloud cover. Hail suppression is any method of reducing the damaging effects of hailstorms by operating on the hail producing cloud (via cloud seeding).[11]

Using a tracer allows better prediction of the results of cloud seeding. A tracer is an environmentally safe, easily detectable substance injected into the atmosphere for the purpose of measuring subsequent atmospheric motion such as trajectory, diffusion, and so forth.[12] Tracers float along with the cloud seeding agent introduced into a cloud, thus allowing scientists to monitor the dispersal of the agents. These results lead to a better understanding of the cloud structure. Commonly used tracers include aluminized glass chaff fibers and sulfur hexafluoride, which are detectable either by radar or by instruments carried through the seeded clouds. Tracers are approved for use by the Environmental Protection Agency and are used in very small quantities.[13]

Another area of weather modification focus concerns fog. Fog dispersal is the elimination or reduction of fog in a limited area by artificial means. Fog enhancement is just the opposite: the creation or increase of fog in a limited area by artificial means.[14] Methods to accomplish fog dispersal are similar to cloud seeding, with the addition that mechanical mixing can also help dissipate fog.

The rest of this study looks into weather modification science, barriers to weather modification use, and possible military applications of weather modification. This glossary helps the reader better understand the more technical aspects of each chapter.

Notes

1. Lt Gen Michael E. Ryan, "NATO Air Operations in Bosnia-Herzegovina: Deliberate Force—29 August 1995–14 September 1995," address to the School of Advanced Airpower Studies, Maxwell AFB, Ala., 7 February 1996.

2. Horace R. Byers, "History of Weather Modification," in *Weather and Climate Modification*, ed. W. N. Hess (New York: John Wiley & Sons, 1974), 14. Others may argue that the US military dabbled in weather modification as far back as the Civil War, but most scientists agree that modern weather modification was born with Project Cirrus.

3. Maj Robert J. Rizza, "Cold Fog Dispersal System (CFDS) End-of-Season Report, FY95," Fairchild AFB, Wash., 92d Operations Support Squadron/OSW Fax, 27 February 1996, 2.

4. Stanley A. Changnon Jr. and W. Henry Lambright, "The Rise and Fall of Federal Weather Modification Policy," *Journal of Weather Modification* 19, no 1 (April 1987): 3.

5. Ye Vostruxov, "Laser and Cloud: Unusual Experiment of Siberian Scientists," translated by SCITRAN, Wright-Patterson AFB, Ohio, Foreign Technology Division, September 1987, 5.

6. Zhou Wei, "Meteorological Weapons," translated by SCITRAN, Wright-Patterson AFB, Ohio, Foreign Technology Division, March 1985, 4.

7. Louis J. Battan, ed., *Glossary of Terms Frequently Used in Weather Modification* (Boston: American Meteorological Society, 1968), 57.

8. Chairman of the Joint Chiefs of Staff Instruction (CJCSI) 3810.01, *Meteorological and Oceanographic Operations,* 10 January 1995, 2.

9. Ibid.

10. Battan, 13.

11. Ibid., 30.

12. Ibid., 53.

13. James A. Heimbach Jr. and William D. Hall, "Observations and Modeling of Valley-Released Silver Iodide Seeding over the Wasatch Plateau," address to the American Meteorological Society Convention, Atlanta, Ga., 30 January 1996.

14. Battan, 27.

Chapter 2

An Overview of Weather Modification

Introduction

This chapter reviews the science and methods of weather modification. It also forecasts likely trends and developments for weather modification for the next ten years and examines the factors driving them.

Manipulations of the local atmosphere date back to the beginning of recorded time. Primitive man used spells, dances, rituals, and prayers to encourage needed rains.[1] These efforts do not necessarily depend upon high technology. For example, the use of smudge pots to keep the air in citrus groves above freezing is a type of weather modification. The smoke from the smudge pots holds in the warmth, keeping the air above a critical temperature threshold. The thermostats and walls of our homes are man-made mechanisms to manipulate the atmosphere around us. Although these methods naturally led to grander attempts at controlling the temperature and humidity in our atmosphere, they do not constitute weather modification. The first scientifically controlled and monitored effort generally recognized by the meteorological community as constituting weather modification occurred in 1948, when Dr. Irving Langmuir first experimented with artificially seeding clouds in order to produce rain. His experiments showed positive results, sparking tremendous interest in the field nearly overnight.[2]

Most BWM efforts focus on four general areas: precipitation enhancement, hail suppression, fog dispersal, and snow augmentation.[3] All four areas are of commercial interest, spurring continued research. Agricultural interests continue to focus on precipitation enhancement to alleviate occasional drought, while hail suppression is important in reducing crop damage. The aviation community continues to explore the means needed to disperse fog in order to improve airport efficiency and safety as well as on-time rates. Ski resort operators use snow augmentation techniques in order to supplement the natural snowfall. In addition, local communities depending on snowpack for drinking water occasionally use snow augmentation to increase winter snowfall.[4]

The Science of Weather Modification

Weather phenomena such as rain, snow, hail, and fog are the result of atmospheric processes ranging in scale from global circulation patterns to water molecule interactions resulting in droplet creation. Between these interaction extremes are several levels of disturbances, from large scale cyclones covering thousands of square kilometers down to individual convective clouds that lead to thunderstorms. These processes interact in an extremely complex fashion. All are interdependent, with the energy released in small scale disturbances feeding the development and movement of the larger scale forces.[5]

Weather modification seeks to change the interactions between the various levels of activity. These changes, made on a small scale, will hopefully lead to larger scale changes and cause the desired change in the weather. The sought-after changes are on a much more modest scale than making climatic changes; only local weather changes are desired.

Weather Modification Methods

Modification of weather can occur in a number of ways:

- altering the available solar energy by introducing materials to absorb or reflect sunshine;
- adding heat to the atmosphere by artificial means from the surface;
- altering air motion by artificial means;
- influencing the humidity by increasing or retarding evaporation; and
- changing the processes by which clouds form and causing precipitation by using chemicals or inserting additional water into the clouds.[6]

In modifying clouds, the idea is to introduce cloud seeding agents into existing clouds in order to induce precipitation, increase precipitation, cause a change in precipitation, or dissipate the cloud entirely. Cloud seeding agents cause the additional formation of ice crystals in clouds. Raindrops form by the coalescence of water droplets on the ice crystals. The presence of more ice crystals means more raindrops can form. Cloud seeding agents work because their crystalline structure closely resembles ice, thereby “fooling” the water droplets into coalescing onto them.[7]

In order to produce precipitation, each liter of air needs only one artificial ice nucleus. Overseeding a cloud causes so many ice crystals to form that the cloud becomes glaciated or made of mostly ice crystals. With few supercooled water droplets left in the cloud, the ice crystals do not grow, and thus evaporate. An excellent example of this can occur through cloud seeding from the air with an abundance of dry ice. Within a few minutes the cloud will dissipate, leaving holes along the path of seeding aircraft.[8]

Introducing cloud seeding agents into the proper cloud regions will cause rain to occur sooner or more heavily than it otherwise would, aiding in the suppression of hail. This deprives hail of the water droplets needed to continue growing, reducing hailstone size and the damage they can cause.[9]

Fog is similar to clouds in that it is a result of a supersaturated atmosphere, except that it is located at the surface of the earth. Fog classification is based on the temperature at which it exists. There are three basic types of fog: warm fog (above 0° C), cold fog (between –30° and 0° C), and ice fog (colder than –30° C). There are specific means to suppress or eliminate each type of fog.

Warm fog suppression can occur through two methods. One method involves warming the foggy air in order to increase the amount of water it can hold. The warmer the air, the less likely the air will be saturated to the point that fog formation occurs. Often this is only a matter of a few degrees of temperature. During World War II, open trenches filled with gasoline or other fuel lined the runways of bomber air bases in England. These trenches were set ablaze during foggy periods. The fog often lifted as a result, allowing planes to take off and land that might not have otherwise been able to do so. Later attempts to use similar systems at US commercial airports failed due to costs, aesthetic objections, and the effect on airline passengers of seeing a runway apparently ablaze.[10]

The other method to suppress warm fog is to mix it with drier air. This mixing causes the water droplets in the fog to evaporate. Large fans, helicopter downwash, or running airplane engines can all be used to accomplish this. One added bonus of using jet airplane engines is that the air is warmed as it passes through the engine, increasing the efficiency of the process.[11]

Introducing a cloud seeding agent into a cold fog can increase visibility even if it does not cause complete fog dissipation. The method is similar to cloud seeding for precipitation enhancement, in that the agent causes fog droplets to form into larger droplets. The larger droplets, unable to remain suspended in the air, fall to the surface. This increases visibility by thinning the fog. Another cold fog dispersal method involves causing the supercooled water droplets to freeze and "snow" out of the fog. The introduction of dry ice or other seeding agents can accomplish this most efficiently.[12]

The best way to suppress ice fog is by attempting to disrupt its formation. The amount of energy needed to do this is quite large. As a result, most ice fog-prone locations simply try to eliminate the source of moisture responsible for the fog. For instance, Eielson AFB, Alaska, set out to eliminate as many sources of water vapor around the base as possible. Many smaller power plants around the base, burning diesel or coal, were eliminated with the construction of one central power plant. Such measures can greatly reduce emissions containing unwanted water vapor, but ice fog can remain a persistent problem. Reductions in visibility due to ice fog occur even as aircraft run up their engines and take off.[13]

Another type of weather modification is the suppression of lightning. The US Forest Service conducted several experiments in this area of BWM during the 1960s and 1970s hoping to reduce the number of forest fires caused by lightning. Scientists thought seeding clouds over forests would reduce the electrical potential of clouds with respect to the ground. The introduction of a cloud seeding agent would cause the formation of more ice crystals, resulting in less electrification of the cloud. However, causing a massive increase in ice crystals reduced the amount of precipitation from the cloud (overseeding). The reduced rainfall worked against the overall objective of reducing forest fires, causing the experiments to be abandoned in 1973.[14]

Each of these weather modification types has commercial applications, and several companies exist to practice these types of BWM. US government-sponsored BWM research, however, is on the decline. Annual government funding (both state and federal) peaked in FY77 at $19 million. In 1992 the funding level fell to $5 million.[15] The current emphasis on global climate change (receiving $400 million in federal research funding in FY91), coupled with continued cutting of overall government expenditures, does not bode well for increased BWM research funding.[16]

Future Benign Weather Modification Trends

Changing public concerns, however, may cause the emphasis in atmospheric research to move towards BWM. At a recent conference on weather modification, Dr. Joseph Golden of the National Oceanic and Atmospheric Administration (NOAA) Office of Oceanic and Atmospheric Research at Silver Spring, Maryland, stated that "regional water issues will dominate weather modification for the next 10 years."[17] Water resources in the Midwest are being strained by continued drainage of underwater aquifers as population growth and accompanying water usage increases. International concern over water rights continues to increase as countries vie for dwindling resources. Two hundred fourteen river basins around the world are shared by more than one country, with most rivers in Africa and Europe being multinational.[18] These pressures are likely to encourage efforts to squeeze more rain out of clouds through weather modification techniques.

Dr. Golden also sees three new likely areas of weather modification research: ice storm suppression or abatement, hurricane modification, and tornado modification. These three areas, he believes, will be the focus of new weather modification efforts due to recent disasters. For instance, in February 1994 ice storms in the United States caused more than $1 billion in damage. Hurricane Andrew devastated southern Florida in 1992. Tornadoes continue to threaten many areas of the United States and kill an average of 92 people per year.[19] Dr. Golden expects that the impetus to seek economic benefits, as well as technological and computational advances, will spur increased funding of weather modification research.[20]

As Dr. Golden sees it, there are three new developments that now make weather modification of severe storms feasible. The first is the fielding of Doppler weather radars throughout the United States. Installation is nearly complete for almost total US coverage by Doppler radars. These radars give scientists an unprecedented ability to examine the structure and dynamics of weather. Coordination between seeding efforts and radar observations allows researchers to determine optimum cloud seeding timing and location. This increases the cloud seeding efficiency and makes success more likely.

The second development making weather modification more feasible is satellite data collection. New sensors are flying aboard weather satellites, providing better data resolution and coverage of the atmosphere. These increases are important in improving the computer model resolution necessary for predicting weather modification effects.

The third area of advancement having an impact on weather modification is sheer computing power and modeling improvements. High resolution weather depiction models running on super computers are becoming the rule rather than the exception. Computer models now simulate weather for longer time periods more quickly, making determination of weather modification effects easier. These transient 3-D models, along with the ability to display results in graphic form on high resolution screens, improve scientists' abilities to spot promising weather modification opportunities.[21]

These expected improvements in weather modification science focus on the observational aspect of the science, not on the applications technology. The ability to predict BWM effects is critical to the success of the science; recently positive cloud seeding results, proven beyond simply statistical means, hold promise for the application of BWM.[22] The use of Doppler radars coupled with the introduction of tracers in cloud seeding have conclusively shown increases in rain formation within clouds. There is no doubt that seeding clouds can increase rainfall. Since this is the most common method of BWM, more attention can now be focused on refining cloud seeding techniques. This is likely to increase interest in BWM and result in increased funding.

Conclusion

Overall, the BWM field made little progress until quite recently. One reason was the lack of funds for research. To be done right, weather modification experiments require years of effort in order to collect enough data to show results. Most government agencies will not or cannot fund studies beyond a single year, retarding efforts to design multiyear experiments. Another reason for the lack of significant BWM progress is a lack of leadership from the federal government. A national plan to coordinate weather modification experiments has never been developed. A divided effort, dispersed among a variety of agencies, is the norm. Rather than trying to break new ground, BWM experiments tend to concentrate on seeking minor improvements in familiar areas. With the introduction of new observational techniques as well as improved computer modeling of BWM effects, the science is ready to take off once again.[23]

Notes

1. Horace R. Byers, "History of Weather Modification," in *Weather and Climate Modification,* ed. W. N. Hess (New York: John Wiley & Sons, 1974), 4.

2. Irving Langmuir, "Final Report: Project Cirrus," *General Electric Research Laboratory Report No. PL 140,* Schnectady, N.Y., 31 December 1948, 14.

3. "Call for Papers: 45th Annual Meeting of the Weather Modification Association," *Bulletin of the American Meteorological Society* 76, no. 11 (November 1995): 2314.

4. Stanley A. Changnon Jr., "Where Does Weather Modification Fit within the Atmospheric Sciences?" *Journal of Weather Modification* 24 (April 1992): 118.

5. John M. Wallace and Peter V. Hobbs, *Atmospheric Science: An Introductory Survey* (New York: Academic Press, 1977), 28–29.

6. Morris Neiburger and H. K. Weickmann, "The Meteorological Background for Weather Modification," in *Weather and Climate Modification,* ed. W. N. Hess (New York: John Wiley & Sons, 1974), 94.

7. Wallace, 267.

8. Ibid., 266.

9. Joe R. Eagleman, *Severe and Unusual Weather* (New York: Van Nostrand Reinhold Co., 1983), 284–85.

10. Louis J. Battan, ed., *Glossary of Terms Frequently Used in Weather Modification* (Boston: American Meteorological Society, 1968), 27.

11. Bernard A. Silverman and Alan I. Weinstein, "Fog," in *Weather and Climate Modification,* ed. W. N. Hess (New York: John Wiley & Sons, 1974), 356–58.

12. Eagleman, 282–83.

13. Silverman and Weinstein, 381.

14. Stanley A. Changnon Jr. and W. Henry Lambright, "The Rise and Fall of Federal Weather Modification Policy," *Journal of Weather Modification* 19, no. 1 (April 1987): 4.

15. Changnon, 121.

16. Ibid.

17. Joseph H. Golden, "On Future Prospects for Severe Weather Modification," address to the American Meteorological Society Convention, Atlanta, Ga., 30 January 1996.

18. Arthur Westing, *Global Resources and International Conflict: Environmental Factors in Strategic Policy and Action* (New York: Oxford University Press, 1986), 97.

19. Thomas P. Grazulis, *Significant Tornadoes: 1680–1991* (Saint Johnsbury, Vt.: Environmental Films, July 1993), 14.

20. Golden.

21. Ibid.

22. Joe Gelt, "Weather Modification: A Water Resource Strategy to Be Researched, Tested Before Tried," *Arroyo* 6, no. 1 (Spring 1992): 9.

23. Changnon and Lambright, 9.

Chapter 3

Barriers to Weather Modification

Introduction

The US military has used BWM in the past, with positive results. As recently as three years ago the USAF was still showing a cost benefit due to the operation of the Fairchild AFB cold fog dispersal system.[1] Yet the military has not conducted research into BWM since the mid-1970s and has no future plans to do so. This chapter reviews several reasons why the military does not currently embrace weather modification: scientific concerns, legal concerns, and moral or ethical concerns.

Scientific Concerns

Weather modification is grounded in physical principles applied to a chaotic, complex atmosphere. These principles can interact, causing unexpected results. For instance, attempts to lift fog by mechanical mixing (trying to blow fog away with aircraft engines) can make the fog worse under some circumstances. If by blowing air into the fog one increases the number of condensation particles, the water vapor present will condense onto those particles. Thus the fog can become worse (lower visibility) even though the intention was to increase the visibility. This is one example where weather modification can produce unintended effects.

In the late 1940s and the 1950s many saw weather modification as a promising science of the future. Several commercial activities sprang up overnight after the well-advertised efforts of Project Cirrus (the first scientific cloud seeding endeavor), and they took on the big problems from the start. In 1949 the city of New York became especially concerned about its dwindling water supply. Based on Project Cirrus, the city hired a recommended weather modification expert to make it rain, increasing the water in New York reservoirs. While it did eventually rain, those involved had no proof that they caused the event to occur.[2]

Similar efforts were made throughout the United States and the rest of the world during these years, all with unproven results. That was the crux of the problem: How do you prove that you, and not Mother Nature, caused it to rain? Scientists and the public voiced similar concerns for all other types of weather modification.

Because of this uncertainty, the initial euphoria about the promise of weather modification wore off by the mid-1960s. The public could not be shown a definitive example of a weather modification success. The failures of weather modification attempts usually received more publicity.

Part of the problem was that practical application of weather modification occurred before science could explain why weather modification worked. The temptation was too great to overcome drought conditions as soon as possible. Weather modification offered a chance to bring much needed rains to farmers and large population centers desperate for precipitation. Commercial efforts ignored the use of the scientific method to prove their ability to successfully modify weather. For instance, in order to prove that BWM made a cloud produce rain, leaving an identical cloud unseeded is necessary in order to provide an experimental control. With so few promising situations for weather modification, such control efforts were often ignored. When farmers want it to rain, they do not want a promising cloud "skipped" since it, too, can produce rain. For commercial success, rain was all the proof needed. For scientific success, controls are necessary.[3]

This situation leads to another part of the problem: Conditions must be perfect for weather modification to work. Weather modification does not "create weather," it simply takes existing weather and changes it marginally. Making rain from a cloudless sky is impossible. Alleviating a drought requires the presence of suitable clouds for seeding in order to generate rain. Certain techniques of fog dissipation require a narrow temperature range. Cold fogs are not conducive to warm fog dissipation techniques and vice versa. Unfortunately when one needs the weather changed the timing may not be perfect.

Another scientific concern is rooted in chaos theory. The earth's atmosphere is considered the classic example of a chaotic system. The "butterfly effect" is an oft-quoted example of a cause-and-effect relationship based on the tenets of chaos theory. In the example, chaos theory states that, because the earth's atmosphere is chaotic, the simple action of a butterfly flapping its wings in Beijing is enough to cause a subtle change leading to, say, a tornado in Illinois (or any other Midwestern state) at some future date.[4]

The butterfly, however, did not cause the tornado in Illinois. Rather, the set of conditions in the atmosphere in Illinois was such that the effect caused by the butterfly flapping its wings was just enough to create the perfect conditions for a tornado to form. It could be just as likely that a moth flapping its wings in Chile would cancel out the effects of the butterfly. Chaos is all about many subtle variations in a system that make the system extremely difficult to understand and predict.[5]

The scientific concern regarding chaos theory is that any input into the atmospheric "system" via weather modification will result in some unknown and unforeseen output somewhere else. The more chaotic a system is, the more sensitive the system is to small perturbations. Why make a system more chaotic and unpredictable by introducing man-made perturbations? On the other hand, if the system is so chaotic, why worry about disturbing it?

A recent article points out, though, that chaos may be used beneficially to shape a system's actions. The third *International Sun-Earth Explorer Satellite (ISEE-3)* was launched in 1978 by the National Aeronautics and Space Administration (NASA) in order to monitor solar activity. This satellite orbited at a libration point, a point of equal gravitation attraction between Earth, the Moon, and the Sun. Seven years after launch NASA decided to send the satellite into a rendezvous orbit with an approaching comet in order to observe closely the comet's coma, or head. In order to make the rendezvous most efficiently, *ISEE-3* was "nudged" out of its orbit in such a way as to cause it to fly by the Moon a number of times. This allowed the satellite to pick up speed with each consecutive fly by, enabling it to reach the comet on time. With the smallest use of fuel onboard the spacecraft, NASA was able to achieve a tremendous change. The chaos in the satellite's orbit gave NASA an ability to control the spacecraft's position that it could not have otherwise had.[6]

Most scientists feel it is important to eliminate chaos in order to make sense of a system. The effort described above with the satellite illustrates the idea of working with chaos in order to adjust a system. It may turn out that it is more efficient to design chaos into a system rather than try to remove it. In other words, chaos might actually be useful.[7]

These examples are different ways of pointing out the same scientific concern: It is hard to show definitive proof of BWM success. How do researchers know that they caused the change in weather when it could have changed due to natural climatic variability? There are methods available today that show researchers whether their attempts at BWM are succeeding. Doppler weather radar will show whether the amount of precipitable water droplets in a cloud is increasing due to cloud seeding. The researcher, though, can never be completely sure that the efforts caused the increase.

For instance, a study suggested that silver iodide seeding can trigger production of secondary ice nuclei by some organic means. This research suggests that fields sprayed with silver iodide release secondary ice nuclei particles at 10-day intervals. These releases could account for inferred increases in precipitation one to three weeks following seeding in several earlier projects. If this is the case, then scientific concerns are even more valid. There may be some unknown coupling between cloud seeding materials and the biosphere. If true, many cloud seeding experiment results are contaminated by bad data. Thus, not only is the weather modification community faced with daunting physical science processes such as the natural variability of meteorology, but they also face the possibility of responses to seeding through biological processes.[8]

Legal Concerns

Not everyone wants it to rain at the same time. For instance, while farmers may want rain to help their crops, a resort owner may want sunny skies for the tourists. These competing interests may lead to the involvement of the legal profession.

Weather modification offers a unique problem when it comes to property rights. Who owns the clouds and the rain in the clouds? When the first cloud seeding experiments in the late 1940s and early 1950s were advertised to the general public, litigation began between the modifiers and those supposedly affected by the weather modification results. Early state court interpretations held that the clouds and the rain in them belonged to those underneath them, as if people on the ground had “mineral rights” to the air above them. This was quickly overturned in favor of the idea that there are no vested property rights in clouds or the moisture in them. In other words, rain belongs to everyone. Interestingly enough, this idea is not as accepted in the western United States as in the East, because the West has had a long history of fighting for private water and mineral rights. However, the idea still stands that the sky above belongs to everyone.[9]

Assessing legal liability is also a problem concerning weather modification: If there is a flood (or some other disaster), who did what to whom? The defendants in such a case are the weather modifier and that person’s or organization’s sponsor. Often that sponsor is a government agency. However, it can be much harder to identify the injured party or parties. First, it is hard to prove that a particular weather event that may have harmed someone was caused by weather modification. Second, while some in an area may feel they were “harmed” by a modified-weather event, others may have benefited from the same event. For instance, a case in the early 1950s pitted a resort owner in upstate New York against a commercial weather modification effort to increase rain for New York City reservoirs. Even though the resort owner “may” have been hurt by the increased rainfall, the court found that the benefit to the millions needing the water far outweighed the inconvenience to the owner.[10]

To increase public acceptance of weather modification, some states levy a tax to help pay for BWM. In this way the public has a stake in the effort itself. Other states regulate weather modification efforts by issuing licenses to operators before such efforts. In order to obtain a license, operators must show they are competent and have a firm understanding of all possible consequences of their efforts. In this way the government protects the public from “snake oil” weather modifiers as well as incompetent practitioners of weather modification.[11]

Since most cloud seeding efforts are at a local level, regulation also occurs at the local or state level. In other words, the scale of intervention fits the scale of the activity. The only federal regulation concerning weather modification is the requirement for all those who conduct such efforts to report those efforts to National Oceanic and Atmospheric Administration and the Department of Commerce.[12]

Note that all these cases referred to cloud seeding efforts to enhance precipitation. Efforts to modify more localized weather events, like fog, are not heavily regulated. On the other hand, efforts to modify more violent weather like hurricanes would come under close international scrutiny. Getting approval for such an effort would be extremely difficult, probably involving the United Nations and the State Department. In general, the greater the number of people affected by the proposed BWM, the higher the approval level necessary.[13]

There are also international legal concerns with respect to weather modification. The United States is a signatory to the 1978 United Nations Convention on the Prohibition of Military of any Other Hostile Use of Environmental Modification Techniques or the ENMOD Treaty. This is the only international document dealing with weather modification that specifically outlaws military use of weather modification as a weapon. However, the language of the treaty is vague and open to interpretation. For instance, the Republic of Korea interprets the treaty to mean that deliberately changing the natural state of rivers is an attempt at environmental modification. In other words, the deliberate destruction of dams to cause flooding is considered illegal by South Korea's interpretation of the ENMOD Treaty.[14] Of critical importance are the treaty's three limitations imposed on military use of environmental (weather) modification. Weather modification cannot be used by the military or as a weapon if it will cause, "widespread, long lasting, and severe effects." These limitations are open to widely ranging interpretation.[15]

In order to clarify the Department of Defense's interpretation of the ENMOD Treaty, the Joint Chiefs of Staff issued an instruction, with the latest version being issued on 10 January 1995. The Chairman of the Joint Chiefs of Staff Instruction (CJCSI) 3810.01, *Meteorological and Oceanographic Operations*, interprets the terms *widespread*, *long lasting*, and *severe* as follows:

1. Widespread. Encompassing an area on the scale of several hundred square kilometers.
2. Long lasting. Lasting for a period of months, or approximately a season.
3. Severe. Involving serious or significant disruption or harm to human life, natural and economic resources, or other assets.[16]

Even within these limitations, there is a lot of room for weather modification efforts by the military. Currently, however, the US military interprets the ENMOD Treaty as allowing no involvement with weather modification efforts. As mentioned earlier, the only active weather modification effort involving the US military began before the treaty ratification in 1978.

In summary, few court cases have been successfully argued against weather modification efforts due to the lack of laws, difficulty in obtaining evidence, and "fuzziness" of the results of BWM. The United States has signed a UN treaty banning weather modification given the previously mentioned limitations, and the military supports that treaty by limiting its use of weather modification as a weapon.

Moral or Ethical Concerns

This author has personally witnessed the anger some people (many of them meteorologists) feel when the idea of military weather modification, benign or not, is mentioned. Their arguments against weather modification fall generally into three categories: opposition to interfering with the natural order, concern for the environment, and opposition to the indiscriminate nature of weather modification use.

Many people base their ideas on misconceptions. Early weather modification pioneers were often responsible for those misconceptions. These experts were very sensitive to criticism, making them exaggerate the perception of negative feelings towards weather modification. However, surveys taken in the late 1960s in areas where weather modification occurred showed public opinion ranging from ambivalence to muted support.[17]

While there have been sporadic protests against weather modification efforts, they have been few in number and small in size. Weather modifiers, however, have shown themselves to be especially sensitive to even limited criticism. Unfortunately, their tendency is to become more secretive about their work. This works against them in the long run since most efforts will, sooner or later, be discovered.[18] The more successful weather modification efforts have been those which advertised the intention and scope of the effort before the action began. In addition, they often generate the greatest public support.[19]

Still, feelings run deep when it comes to altering what many consider to be "God's domain." Animosity towards weather modification grew in the early 1970s as the environmental movement gained momentum. This, coupled with the revelations concerning weather modification use in the Vietnam War (Project Popeye), was a double blow to weather modification efforts.[20] The environmental movement continues to grow today, making it even more difficult to propose weather modification experiments and operations. Unfortunately weather modification is viewed as "harming" the environment, even though BWM simply alters weather by enhancing or suppressing it. Simply changing the weather from one form to another may not harm the environment, since it could have occurred even without human intervention. Such arguments, however, usually fall on deaf ears.

Another aspect of weather modification that strikes fear in some people is its apparently indiscriminate nature. People often picture weather modification being similar to chemical and biological warfare: It affects everyone, civilians and military alike. The ENMOD Treaty addresses this by prohibiting weather modification from occurring over a large area. Today weather modification efforts can be focused down to a single storm, for instance, when that storm is a potential hail-producer. While BWM is not capable of making pinpoint alterations, the science has progressed to a point where limiting the effects to a few square miles or less (such as a runway being cleared of fog) is possible.

Conclusion

Many of the current barriers to BWM stem from an uninformed public. Many still remember the days when weather modification promised much yet delivered little. Others consider all weather modification to be wrong, lumping together BWM with science-fiction tales of generating hurricanes to strike an enemy (guilt by association). Legal authorities have kept their hands off the issue, only issuing the barest minimum of laws and regulations. States make most laws concerning BWM, and differences in those laws can actually prevent operators from practicing BWM. For instance, even if one state allows weather modification, an adjacent state may prohibit it. The situation could get very difficult if a seeded cloud were to drift across the state line.

However, none of these barriers is insurmountable. Currently the military unnecessarily equates limitations on hostile weather modification with limitations on all weather modification. A distinction between hostile and benign weather modification is important since few, if any, of the concerns mentioned here apply to BWM. If BWM makes sense, overcoming these obstacles is possible.

Notes

1. Maj Robert J. Rizza, "Cold Fog Dispersal System (CFDS) End-of-Season Report, FY95," Fairchild AFB, Wash., 92d Operations Support Squadron/OSW Fax, 27 February 1996, 3.
2. Horace R. Byers, "History of Weather Modification," in *Weather and Climate Modification*, ed. W. N. Hess (New York: John Wiley & Sons, 1974), 22.
3. Robert D. Elliot, "Experience of the Private Sector," in *Weather and Climate Modification*, ed. W. N. Hess (New York: John Wiley & Sons, 1974), 51.
4. James Gleick, *Chaos: Making a New Science* (New York: Penguin Books, 1987), 20–23.
5. Ibid.
6. William Brown, "Mathematicians Learn How to Tame Chaos," *New Scientist* 134, no. 1823 (30 May 1992): 16.
7. Ibid.
8. William R. Cotton and Roger A. Pielke, *Human Impacts on Weather and Climate* (New York: Cambridge University Press, 1995), 60.
9. Ray J. Davis, "Weather Modification Litigation and Statutes," in *Weather and Climate Modification*, ed. W. N. Hess (New York: John Wiley & Sons, 1974), 768.
10. Ray J. Davis, "Weather Modification Law as a Prototype for Local Control of Inadvertent Weather and Climate Change," *Journal of Weather Modification* 24, no. 1 (April 1992): 122.
11. Ibid., 123.
12. Ibid., 124.
13. Davis, "Weather Modification Litigation and Statutes," 772–73.
14. *Multilateral Treaties Deposited with the Secretary-General: Status as of 31 December 1992* (New York: United Nations Publications, 1993), 810.
15. Ibid.
16. Chairman of the Joint Chiefs of Staff Instruction 3810.01, *Meteorological and Oceanographic Operations*, 10 January 1995, 2.

17. J. Eugene Haas, "Sociological Aspects of Weather Modification," in *Weather and Climate Modification*, ed. W. N. Hess (New York: John Wiley & Sons, 1974), 808.
18. Ibid.
19. Ibid.
20. Charles C. Bates and John F. Fuller, *America's Weather Warriors: 1814–1985* (College Station, Tex.: Texas A&M University Press, 1986), 231.

Chapter 4

Military Applications of Weather Modification

Introduction

The US military virtually ignores current techniques of weather modification. The purpose of this chapter is to examine possible benefits to the military of using existing civilian and military-unique weather modification technology. This chapter reviews current civilian efforts in weather modification with potential for military applications. It addresses possible weather modification applications or techniques that are unique to military operations but are not yet being researched. The final section examines the feasibility and efficacy of using weather modification for military operations.

Current Methods Applicable to Military Operations

The one type of weather modification still used by the US military is fog suppression. Fairchild AFB in Spokane, Washington, has the only operational fog suppression system in the US military. Installation of this system occurred in the early 1970s as part of Project Cold Wand, an experiment to explore the possibilities of fog suppression.[1] Two other systems were installed, one at Elmendorf AFB, Alaska, and the other at Hahn Air Base (AB), Germany. Closure of the system at Elmendorf AFB was due to a mission change in the late 1980s. The new mission commanders no longer felt the need to fund this system due to little perceived benefit.[2] The Hahn AB system closed before control of the base reverted to German authorities.

The Fairchild system consists of 23 sites around the base equipped with propane sprayers. Liquid propane, cooled to –43° F, is injected into the fog when certain other meteorological conditions are met. At the proper time, the weather station activates the system from an on-site computer. The propane causes the water droplets present in the fog to freeze and precipitate out as ice crystals. The process takes about an hour, with the hope that winds will push the hole opened by the system over the runway. By reducing the amount of water vapor present, the fog lifts and visibility increases. This allows more aircraft to take off and land than would have been possible given the reduced visibility.[3]

While the system saved money throughout the 1980s, its use today is rare. In fact, from 19 October 1994 to 5 January 1996, the system lost nearly $18,000. This is due primarily to an increased reluctance to use the system to assist in generating training sorties. Use of the system is now allowed only when conditions are right and there is a need to assist an operational, nontraining Air Mobility Command mission. The odds of such an occurrence are slim, which explains use of the system only three times in the past two years. Meanwhile the system must be maintained, and supplies must be purchased, which contributes to the overall operating loss.[4]

Part of the reluctance to use the system stems from a legal concern. When the system is turned on, frozen precipitation is deposited on surfaces around the base, which can occur on roads used by civilians. Such unexpected slippery roads could lead to automobile accidents, and the leadership at Fairchild is sensitive to possible legal action as a result.[5]

Although this system has shown an ability to clear cold fog, it uses technology from the early 1970s. Upgrades occurred several times previously to make it more automated and easier to monitor. However, more recent advances in cold fog dispersal research have not been incorporated due to the cost of significantly changing the system. Further upgrades to the system seem unlikely given the infrequency of its use.[6]

Warm fog dispersal has not been tried as an operational BWM technology by the military. Warm fog requires a totally different technique for dissipation from cold fog. Warm fog is also much more common than cold fog as it can occur whenever the temperature is above 32° F and the air is saturated. Overall, warm fog accounts for nearly 95 percent of the ground fog in the continental United States (CONUS). Ground fog impacts one to two percent of all flights at bases in the United States. In Europe this percentage rises to two to four percent.[7]

One promising technology yet to be proven is the use of lasers to dissipate warm fog. Dr. Edward Tomlinson, in a report published in 1992, undertook a study to review the feasibility of using lasers to evaporate the water droplets in fog. Illumination of the fog with a 10.2 micron laser (an infrared frequency) causes the water droplets to rise in temperature. This rise leads to the evaporation of the droplet, causing an increase in visibility.[8]

The laser system described in his report can be deployed around an airfield with no harm coming to those in the area during use. The liquid propane release in the Fairchild AFB system can take an hour to produce the needed rise in visibility. Dr. Tomlinson's study shows that a laser system could achieve the same results in minutes. He estimates that the money needed for a proof of concept demonstration, new laser development, installation and initial operational development would amount to $20 million. However, subsequent systems would be cheaper because of earlier payment of fixed development costs. Tomlinson estimates that a demonstration of this method would cost between $600,000 to $750,000. Development of a deployable version of such a system is also possible.[9]

Why did this effort stop at phase one? According to Dr. Tomlinson, there was not a stated, hard requirement for such technology. While warm fog is a significant problem for airports, few believed a practical technology would emerge to overcome it. Instead, technologies were developed to "work around" the problem. While scientists like Dr. Tomlinson see promise in this technology development, lack of a technology "pull" from operational customers will restrict development.[10]

Other, less esoteric methods of fog dissipation are available today in the civilian community. Considering fog simply to be a cloud on the ground leads to other methods, such as seeding from the air. Experiments have shown the use of cloud seeding agents like silver iodide can cause fog to precipitate or "rain" out. The fog's moisture condenses on the silver iodide particles, forming larger droplets until gravity takes over and drops fall. The effect is rapid, and it can be shaped via a planned dispersion pattern so that the fog only clears where needed. While this is a proven fog dispersal technique, the civilian community does not use it in an operational fashion. This is due mainly to cost and, as stated before, acceptance of the problem itself as a given factor in flight operations.

A related method that was tried but later abandoned by the military is the use of aircraft dry ice seeding to dissipate cold fog. In the late 1960s and early 1970s, specially configured WC-130 aircraft were equipped with a dry ice crusher and dispenser. On a typical mission such aircraft would fly a seeding pattern consisting of between five and 30 parallel lines, each five to six miles long and 0.5 to 1.5 miles apart. This pattern would be flown just above the fog at a distance between 45 and 60 minutes upwind of the area where clearing was desired, with the machine generally dispensing 15 pounds of crushed dry ice per minute. The hole then, hopefully, drifts over the desired area at the desired time. The return on the investment in these operations was significant; during the winter of 1969–70, fog dispersal operations in the United States via this method cost $80,000 but saved $900,000. As weather modification became discredited in the mid-1970s, this method was abandoned.[11]

New techniques being explored by the civilian community include the use of flares attached to aircraft flying through clouds. However, the most promising new developments involve not the seeding but the measurement of the results. Airborne and ground-based Doppler radars now provide real-time data on cloud seeding efforts. The radar data are used to evaluate cloud seeding efforts as well as to adjust those efforts immediately for better results. Another new technology that has been discussed but not yet exploited is the use of remotely piloted vehicles (RPV) to carry measuring instruments through the seeding candidate clouds for nearly instantaneous measurements. The ability of inexpensive RPVs to loiter for extended periods over a given area make them ideal for measuring seeding effects during a storm's life. Current military operations could easily take advantage of all of these techniques.[12]

Future Military BWM Techniques with Civilian Applications

If the military were to pursue BWM with vigor, assistance by the military in civilian BWM applications would be a distinct possibility. There are two significant ways in which the military can use its skill in BWM: through unique application approaches and through unique measurement techniques.

RPVs are quickly becoming an indispensable part of any task force. Mainly used for reconnaissance, RPVs are now becoming larger and carrying heavier payloads. While experiments have not explored this idea, it may be possible to use RPVs to apply seeding agents either to clouds or fog to achieve BWM.

The advantages of using RPVs involve issues of safety as well as expense. What if there is a need to increase visibility over a hostile area? Seeding clouds or fog may be a way to increase visibility for targeting. For the military, using an RPV to carry and disperse a seeding agent means not risking a more expensive airframe over hostile territory. This also lessens the risk to crew members in these situations, making the use of RPVs in contested airspace an attractive option. Given the right configuration, an RPV could carry the seeding agent as well as measure and report back the results of the seeding. For example, one RPV configured to seed and view results could replace portions of the extensive airplane package involved in the CSAR attempt described at the beginning of this study. Such an RPV could clear the fog and search for the downed airmen at the same time. To increase the odds of finding the airmen, several RPVs could fly over a much larger area. Extraction could be quicker due to the ability to pinpoint the location of the downed airmen, increasing the safety of those involved in the mission by reducing exposure to the enemy.

RPVs, because they are cheaper than aircraft and require less maintenance in terms of money and personnel, would also make ideal platforms for civilian seeding activities. Either the military or the civilian sector could develop the RPV, and then lease or lend the aircraft to the other. RPV deployment may also be less obvious, avoiding diplomatic concerns for host nation basing.

Satellite instruments could also provide a unique perspective in measuring BWM effects. As instruments become more sensitive in more wavelength bands, it may be possible to use them to monitor ongoing activities in real time as well as keep an "eye" out for unforeseen weather effects. Satellites have a bigger footprint and can see farther over the horizon than airplanes. Coordination between instruments looking into different wavelengths of the electromagnetic spectrum will give a more complete picture of weather modification efforts.

As military technology advances, every effort should be made to examine whether these advances have any civilian applicability. Only through close coordination between civilians and military researchers, though, will this cross flow of ideas and technology occur.

Purely Military Applications of BWM

Civilian research and methods do not address all needs of the military. Perceived or actual economic benefits drive civilian BWM efforts. Therefore, pursuit of those techniques without any economic benefit by the civilian development community is unlikely. Several military-unique BWM applications are addressed here.

Fog generation could be of significant value to the US military, primarily to obscure the view of enemy reconnaissance platforms (both aircraft and satellites). Military efforts at generating fog have been conducted in order to experiment with ways to dissipate that same fog. However, as with fog dissipation, the conditions must be right to generate and sustain fog. The goal of generating fog deliberately to hide forces from observation or attack is different than previous researcher goals. Therefore, future experiments would have to be tailored for the new objective of hiding military operations via fog generation.[13]

Artificial fog generation occurs through the injection of water into a nearly saturated or saturated atmosphere. Winds must be light or calm, and surface heating must be at a minimum to avoid dissipating the fog too early. One use would be to hinder the employment of precision guided munitions (PGM) against friendly forces, especially those using the infrared (IR) spectrum for acquisition and lock on. Fog is an excellent method of preventing IR weapons from "seeing" enough of a contrast between the background and target to provide firm lock on. Fog could also protect forces from attack by lasers and visually aimed weapons.

One alternative to fog generation is smoke generation. It is not as dependent on ideal atmospheric conditions for success. Military forces on the ground and ocean already use this technique to "hide." However, it only obscures in the visible spectrum, whereas fog can obscure in both the visible and IR portions of the electromagnetic spectrum. Iraq used a form of this when retreating troops set fire to Kuwaiti oil wells at the end of the Gulf War. Great amounts of smoke were produced, greatly reducing visibility over a large area.

Dr. Tomlinson, in his efforts at dissipating warm fog, inadvertently found another way to generate fog. A pulsed laser literally causes water droplets to shatter. The more water droplets per given volume of air, the lower the visibility of the air. His studies showed an initial decrease in visibility, followed by the expected increase in visibility as the water droplets warmed and evaporated. As a result, he recommends the use of a continuous wave laser to avoid this initial decrease in visibility during fog dissipation. When asked about using a pulsed laser to deliberately decrease visibility, he said he felt such a decrease would be greater and more effective the closer the laser is to the fog (or target).[14]

Another possible method of modifying the environment to hinder PGM lock on would be to decrease the temperature contrast between potential targets and the surrounding terrain via heating the local environment. This would involve warming the ambient air around possible friendly targets. The air could be warmed via direct energy inputs by mechanical means or by clearing away clouds, allowing the sunshine to raise the temperature of the surrounding air. Creating clouds to block sunshine would reduce heating of potential friendly targets. The less the temperature contrast between the target and the surrounding environment, the harder it is for an IR PGM to achieve lock on.

One final BWM technique with unique military applications involves millimeter wave (MW) radar. Dr. Tomlinson notes that his numerical simulations showed that larger water droplets evaporated faster than smaller ones. This was due primarily to their larger cross-sectional area; the larger the area of the droplet, the more energy the droplet absorbed and, therefore, the faster it would evaporate. MW radars are being developed to allow airplanes to land in extreme fog conditions. It is possible that a precisely timed effort to decrease the size of larger water droplets working together with the MW radar would reduce the backscatter noise from those larger droplets. This would make the radar more effective in "seeing" through the fog. Hence, Dr. Tomlinson speculates, an MW radar could be made cheaper since it would not have to be as efficient. In turn, the same ability can decrease MW effectiveness. This would help prevent enemy MW radar from finding friendly ground forces.[15]

This brings up the obvious point: Why should the military pursue BWM when development is under way to alleviate weather effects via better sensors and radars? The fact that technology is leading to the development of more "all weather" products shows that weather impacts are recognized by the military. BWM may offer a way to reduce the weather impacts further, and it may be cheaper in the long run.

In addition, BWM development may lead to counter-BWM technique development. Many countries use BWM primarily to enhance or protect agricultural output. There is no evidence that other countries are pursuing military applications for weather modification. As this chapter has shown, though, there are civilian BWM techniques that could easily be transitioned to military applications. Military pursuit of BWM could reveal possible countermeasures to enemy BWM.

Economic Costs and Benefits of BWM

As mentioned earlier, the only currently operational weather modification effort saved the Air Force money until other considerations prevented its efficient use (see chap. 3). There have been other weather modification efforts, however, that have also demonstrated the potential savings from BWM.

Examination of insurance claims from hail damage in North Dakota revealed that, when potential hail producing storms were seeded, damage was reduced in the operational area by 43.5 percent. Estimates showed a benefit-to-cost ratio of eight times the cost of operations. The study results confirmed the value of North Dakota's continuing cloud seeding experiments. The study was not used to "sell" insurance companies on cloud seeding benefits.[16]

While involvement of the US military in hail suppression in CONUS may not be necessary, there is precedence for the military to provide foreign assistance. The Philippine government in 1969 requested and received US military cloud seeding assistance. The effort was to increase rainfall to alleviate drought in the country. Partly in response to the seeding, there was a marked increase in sugar, rice, and corn production.[17] BWM efforts, coordinated through the State Department and carried out by the Defense Department, may be an excellent way to support US allies.

In the past weather modification experiments have been costly and prolonged. In order to gather enough data and to factor out climatological trends, modification experiments ideally last several years. As techniques and observation abilities improve, however, weather modification costs are falling. In addition, fewer necessary case studies in weather modification will mean a decrease in experiment length. This will translate into a more precise ability to apply BWM at the right place and time.

Ultimately, the cost of BWM must be weighed against the operations it will benefit. What cost is too high when measured against the success or failure of a military operation? That decision falls to the commander directing the operation. BWM capability is simply an available tool that may help the commanders. If other techniques (smoke generation, camouflage) achieve the results more efficiently, they should continue to be the commander's tool of choice.

Conclusion

This chapter reviewed current techniques in weather modification and their possible applicability to military operations. All these examples, whether developed by civilian or military researchers, have the potential to benefit military operations and the commander in the field. However, lack of study of military-specific BWM precludes the opportunity to determine BWM efficacy. The next chapter proposes possible next steps if the US military wishes to explore BWM.

Notes

1. Maj Robert J. Rizza, "Cold Fog Dispersal System (CFDS) End-of-Season Report, FY95," Fairchild AFB, Wash., 92d Operations Support Squadron/OSW Fax, 27 February 1996, 3.

2. MSgt William Shacklady, station chief, 3d Operations Support Squadron/OSW Fax, 3 May 1996, 1.

3. Rizza, 5.

4. Maj Robert J. Rizza, "Interim Activity Reports and Final Report to NOAA," 92d Operations Support Squadron/OSW Fax (NOAA Form 17-4A), 21 April 1995, 1.

5 Maj Robert J. Rizza, interviewed by author, 21 April 1996.

6. Rizza, CFDS Report, 3–4.

7. Edward M. Tomlinson, Kenneth C. Young, and Duane D. Smith, "Laser Technology Applications for Dissipation of Warm Fog at Airfields," Phillips Laboratory Report PL-TR-92-2087, Hanscom AFB, Mass., March 1992, 2.

8. Ibid., 5–7.

9. Edward M. Tomlinson, "Re: Warm Fog Dissipation," E-mail to the author, 24 March 1996.

10. Ibid.

11. Bernard A. Silverman and Alan I. Weinstein, "Fog," in *Weather and Climate Modification*, ed. W. N. Hess (New York: John Wiley & Sons, 1974), 367–68.

12. Joseph H. Golden, "On Future Prospects for Severe Weather Modification," address to the American Meteorological Convention, Atlanta, Ga., 30 January 1996.

13. Robert A. Sutherland, "Results of Man-Made Fog Experiment," address to the 1991 Battlefield Atmospherics Conference, Fort Bliss, Tex., 3–6 December 1991, 1.

14. Tomlinson, "Re: Warm Fog Dissipation."

15. Ibid.

16. Paul L. Smith et al., "An Exploratory Study of North Dakota Crop-Hail Insurance Data for Evidence of Seeding Effects," address to the American Meteorological Society Convention, Edmonton, Alberta, Canada, 1987, 89.

17. Capt Henry A. Chary, "A History of Air Weather Service Weather Modification: 1965–1973," Air Weather Service Report AWS-TR-74-247, Scott AFB, Ill., June 1974, 21.

Chapter 5

Conclusion and Recommendations

Introduction

This study examined benign weather modification as a possible option for assisting the military in war and peace. After reviewing briefly the history of scientific weather modification and defining the scope, an explanation of the science and technology of weather modification followed. The barriers to current use by the military of weather modification were then described in some detail. Examples were shown of current civilian techniques at weather modification, their possible use by the military, and some military-unique needs for weather modification. This chapter offers some ideas as to how the military should approach the subject of weather modification in the future. It also details some actions that the military should take in order to begin reusing this potentially valuable tool in war fighting.

Why Weather Modification Now?

Why should the military again explore the use of benign weather modification? Simply, the science and technology offer a way to save both money and lives in military operations.

Until recently the fog dispersion system at Fairchild AFB was a proven money saver. From the fog season (winter) of 1980–81 until the season of 1989–90, the system saved the Air Force $4.5 million. Over 650 departures and nearly 400 recoveries occurred during this same period, accounting for the cost savings as determined by Air Force regulations. The system has paid for itself many times over at this airfield.[1] If the warm fog dispersion method by laser array can prove itself in operational tests, such a system would benefit both military and civilian airports worldwide. A tactical version of a fog dispersion system is now technically feasible. Such a device would be of great help during deployments to unimproved airstrips.

As for strictly military operations, BWM could increase targeting accuracy while helping to reduce collateral damage. If a high value target must be struck with little or no collateral damage, BWM could be used first to ensure that the pilot is able to achieve a lock on with a precision weapon. Keep in mind, however, that the conditions must be right for the use of BWM in the first place. However, having that option in the right situation may help prevent loss of innocent civilian lives near that target.

BWM offers yet another tool for the war planner to use at a critical point in a conflict. BWM can alter the weather to assist friendly operations or deny the enemy protection from the elements. For instance, generating or dissipating clouds can hide friendly forces or expose the enemy. Enhancing precipitation increases available water supplies, potentially assisting both friendly forces and civilians in the affected area. Generating or dissipating fog can mask friendly troops and movements while revealing enemy forces. Weather modification may be the key to success or failure of the mission at a critical moment in a weather-sensitive military operation.

What Will It Take to Work?

The science of weather modification deserves another look by the US military. What follows are a series of recommendations based on the research and conversations held with weather modification experts, both in and out of the military.

Recommendation one: Make a commitment to use benign weather modification.

Any effort to reopen and expand the use of BWM by the military will be met with resistance, both within and outside of the military. Therefore, the senior leadership will need to make clear what efforts are being explored with respect to weather modification. Publicizing these efforts is necessary in order to eliminate all traces of "cloak and dagger" efforts tainting earlier military weather modification efforts. Rewriting the CJCSI on meteorological operations to define legal and illegal BWM would be an excellent first step.

Recommendation two: Make weather modification a dual-use technology.

To attempt BWM in the most economical manner, make weather modification a dual-use effort. Examination of civilian efforts at BWM must be made and exploited first to achieve faster integration into military operations. To this end, assigning a military liaison officer to NOAA, preferably a weather officer, will assure the military of maintaining close contacts with the latest efforts in US civilian weather modification efforts. Because NOAA is responsible for monitoring all weather modification efforts in the United States, liaison with them will give the military an excellent opportunity to monitor the current state of the art in weather modification.

Recommendation three: Make weather modification a joint-use technology.

The Air Force is not the only service to benefit from weather modification efforts. While the Air Force stands to benefit the most from BWM due to its extensive and diverse flying mission, all services will ultimately benefit from BWM efforts. As a result, serious consideration must be given to make BWM a joint effort. Perhaps a joint office with both Navy and Air Force weather officers would be better at proposing military uses of BWM techniques. A joint office also ensures better funding for the effort as well as greater acceptance of weather modification among all the services.

A joint office dealing with military weather modification could also better coordinate military-unique BWM science and applications. Such an office would provide seed money to scientific research into military-specific areas. Feeding these results back to the civilian community for possible civilian BWM benefits should be encouraged by this office.

Recommendation four: Determine necessity for a BWM military applications cell.

While it would seem appropriate to establish a BWM cell within the Air Force's Air Weather Service (AWS), the mission may not yet warrant having such a cell created. Whether the scope of the effort deserves having a separate office established would depend on the efforts of the NOAA liaison officer. If an immediate payoff can be realized for military operations, then such a cell makes sense. However, if the military needs several years to fully exploit existing BWM technology, such a cell may be premature.

If enough money and interest are immediately placed in BWM by the military, then such a cell of military expertise is warranted. Establishment of this cell would make best sense at the AWS Combat Weather Facility at Hurlburt Field, Florida. This facility reviews all technology and science for applicability to battlefield weather support. Since BWM can only legally occur at the tactical level of war, the individuals at the Combat Weather Facility would have the best vision of BWM applicability.

Recommendation five: Fund BWM for the long term.

The controversy associated with weather modification efforts in the past demands a slow, methodical pace if the military wishes to pursue BWM. There will be several organizations and individuals highly critical of any effort by the military to use weather modification, no matter how benign it is made. Many will feel that this is an attempt to circumvent the ENMOD Treaty. As a result, advertising successful uses of BWM will help greatly. The economic savings as well as lives spared should always be touted when BWM is used. Any possible benefits to the civilian sector by military BWM must be advertised to generate the greatest possible public relations empathy.

Funding at a multiyear level assures continued interest in BWM by civilian researchers. This avoids previous complaints by researchers and ensures well-thought-of involved BWM experiments where the results are not rushed or skewed by data gaps.

Conclusion

The science of weather modification has progressed while the military has ignored its potential. It is time for the military to rethink benign weather modification, explore its benefits more in depth, and exploit the science for the benefit of all involved.

Notes

1. Maj Robert J. Rizza, "Cold Fog Dispersal System (CFDS) End-of-Season Report, FY95," Fairchild AFB, Wash.," 92d Operations Support Squadron/OSW Fax, 27 February 1996, 5.

Bibliography

Books

Bates, Charles C., and John F. Fuller. *America's Weather Warriors: 1814–1985*. College Station, Tex.: Texas A&M University Press, 1986.

Battan, Louis J., ed. *Glossary of Terms Frequently Used in Weather Modification*. Boston, Mass.: American Meteorological Society, 1968.

Breur, Georg. *Weather Modification: Prospects and Problems*. New York: Cambridge University Press, 1979.

Byers, Horace R. "History of Weather Modification." In *Weather and Climate Modification*. Edited by W. N. Hess. New York: John Wiley & Sons, 1974, 3–44.

Cotton, William R., and Roger A. Pielke. *Human Impacts on Weather and Climate.* New York: Cambridge University Press, 1995.

Davis, Ray J. "Weather Modification Litigation and Statutes." In *Weather and Climate Modification*. Edited by W. N. Hess. New York: John Wiley & Sons, 1974, 767–86.

Eagleman, Joe R. *Severe and Unusual Weather*. New York: Van Nostrand Reinhold Co., 1983.

Elliot, Robert D. "Experience of the Private Sector." In *Weather and Climate Modification*. Edited by W. N. Hess. New York: John Wiley & Sons, 1974, 45–89.

Gleick, James. *Chaos: Making a New Science*. New York: Penguin Books, 1987.

Grazulis, Thomas P. *Significant Tornadoes: 1680–1991*. Saint Johnsbury, Vt.: Environmental Films, 1993.

Haas, J. Eugene. "Sociological Aspects of Weather Modification." In *Weather and Climate Modification*. Edited by W. N. Hess. New York: John Wiley & Sons, 1974, 787–811.

Multilateral Treaties Deposited with the Secretary-General: Status as *of 31 December 1992*. New York: United Nations Publications, 1993.

Neiburger, Morris, and H. K. Weickmann. "The Meteorological Background for Weather Modification." In *Weather and Climate Modification*. Edited by W. N. Hess. New York: John Wiley & Sons, 1974, 93–135.

Silverman, Bernard A., and Alan I. Weinstein. "Fog." In *Weather and Climate Modification*. Edited by W. N. Hess. New York: John Wiley & Sons, 1974, 355–83.

Wallace, John M., and Peter V. Hobbs. *Atmospheric Science: An Introductory Survey.* New York: Academic Press, 1977.

Westing, Arthur. *Global Resources and International Conflict: Environmental Factors in Strategic Policy and Action.* New York: Oxford University Press, 1986.

Addresses

Barnes, Arnold A. Jr. "Weather Modification." Address. Air Force 2025 Research Group, Maxwell AFB, Ala., 29 November 1995.

Golden, Joseph H. "On Future Prospects for Severe Weather Modification." Address. American Meteorological Society Convention, Atlanta, Ga., 30 January 1996.

Heimbach, James A. Jr., and William D. Hall. "Observations and Modeling of Valley-Released Silver Iodide Seeding over the Wasatch Plateau." Address. American Meteorological Society Convention, Atlanta, Ga., 30 January 1996.

Ryan, Lt Gen Michael E. "NATO Air Operations in Bosnia-Herzegovina: Deliberate Force—29 August 1995–14 September 1995." Address. School of Advanced Airpower Studies, Maxwell AFB, Ala., 7 February 1996.

Smith, Paul L., et al. "An Exploratory Study of North Dakota Crop-Hail Insurance Data for Evidence of Seeding Effects." Address. American Meteorological Society Convention, Edmonton, Alberta, Canada, 1987.

Sutherland, Robert A. "Results of Man-Made Fog Experiment." Address. 1991 Battlefield Atmospherics Conference, Fort Bliss, Tex., 3–6 December 1991.

Instructions

Chairman of the Joint Chiefs of Staff Instruction 3810.01. *Meteorological and Oceanographic Operations*, 10 January 1995.

Periodicals

Brown, William. "Mathematicians Learn How to Tame Chaos." *New Scientist* 134, no. 1823 (30 May 1992): 16.

"Call for Papers: 45th Annual Meeting of the Weather Modification Association, 23–24 May 1996, Pacific Grove, California." *Bulletin of the American Meteorological Society* 76, no. 11 (November 1995): 2314.

Changnon, Stanley A. Jr. "Where Does Weather Modification Fit within the Atmospheric Sciences?" *Journal of Weather Modification* 24, no. 1 (April 1992): 118–21.

Changnon, Stanley A. Jr., and W. Henry Lambright. "The Rise and Fall of Federal Weather Modification Policy." *Journal of Weather Modification* 19, no. 1 (April 1987): 1–12.

________. "Experimentation Involving Controversial Scientific and Technological Issues: Weather Modification as a Case Illustration." *Bulletin of the American Meteorological Society* 71, no. 3 (March 1990): 334–44.

Davis, Ray J. "Black Clouds and Silver Iodide: Public Safety and Weather Modification Law." *Journal of Weather Modification* 23, no. 1 (April 1991): 63–66.

________. "Weather Modification Law as a Prototype for Local Control of Inadvertent Weather and Climate Change." *Journal of Weather Modification* 24, no. 1 (April 1992): 122–25.

Gedzelman, Stanley David. "Chaos Rules." *Weatherwise* 47 (August-September 1994): 21–26.

Gelt, Joe. "Weather Modification: A Water Resource Strategy to Be Researched, Tested Before Tried." *Arroyo* 6, no. 1 (Spring 1992): 1–9.

Lambright, W. Henry. "A State Perspective on the Development of Weather Modification: The Case of Illinois." *Journal of Weather Modification* 22, no. 1 (April 1990): 143–51.

Milbrath, Lester W. “Climate and Chaos: Societal Impacts of Sudden Weather Shifts.” *The Futurist* 28 (May-June 1994): 26–28.

Monastersky, R. “Can Science Whip Up a Salve for Global Wounds?” *Science News* 148 (30 September 1995): 222.

Nordwall, Bruce D. “Millimeter-Wave Radar Tested as Landing Aid.” *Aviation Week & Space Technology* 142, no. 20 (15 May 1995): 55–56.

Orville, Harold D. “Report on the Sixth WMO Scientific Conference on Weather Modification.” *Bulletin of the American Meteorological Society* 76, no. 3 (March 1995): 372–73.

Phillips, Kathryn. “Breaking the Storm.” *Discover* 13 (May 1992): 62–69.

Posey, Carl. “Hurricane Omni: Scenario for Seeding an Imaginary Storm.” *Omni* 16 (March 1994): 14.

“Win the Information War.” *Army* 45, no. 10 (October 1995): 218–88.

Reports, Theses, and Papers

Asmus, Robert B. “Environmental Concerns of the Joint Task Force Commander.” Newport, R. I.: Naval War College, 1992.

Brown, Ronald R. “Military Applications of Weather Modification: Legal Options.” Maxwell AFB, Ala.: Air Command and Staff College, 1976.

Brownfield, Harold H. “Weather Modification and Climate Control as an Element of Military Power.” Maxwell AFB, Ala.: Air Command and Staff College, 1965.

Centner, Christopher, et al. “Environmental Warfare: Implications for Policymakers and War Planners.” Maxwell AFB, Ala.: Air Command and Staff College, 1995.

Chary, Capt Henry A. “A History of Air Weather Service Weather Modification: 1965–1973.” Air Weather Service Technical Report AWS-TR-74-247. Scott AFB, Ill., June 1984.

Cobb, James T. Jr., et al. “Project Popeye: Final Report.” China Lake, Calif.: Naval Weapons Center, 1967.

Langmuir, Irving, et al. “Final Report: Project Cirrus.” General Electric Research Laboratory No. PL 140, Schenectady, N.Y., 31 December 1948.

Merlo, Anthony L. “Is Weather Modification Defense Feasible?” Maxwell AFB, Ala.: Air War College, 1966.

O’Neal, Joe R. “Military Aspects of Weather Modification.” Maxwell AFB, Ala.: Air Command and Staff College, 1967.

Rizza, Maj Robert J. “Cold Fog Dispersal System (CFDS) End-of-Season Report, FY 95.” Fairchild AFB, Wash.: 92d Operations Support Squadron/OSW, 27 February 1996.

________. “Meteorological Conditions, Theory of Operations and History, CFDS.” Fairchild AFB, Wash.: 92d Operations Support Squadron/OSW, 21 April 1995.

Stralka, Raymond J. “Some Economic and Military Aspects of Weather Modification.” Maxwell AFB, Ala.: Air War College, 1970.

Tomlinson, Edward M., Kenneth C. Young, and Duane D. Smith. “Laser Technology Applications for Dissipation of Warm Fog at Airfields.” Hanscom AFB, Mass.: Phillips Laboratory, March 1992.

Vostruxov, Ye. “Laser and Cloud: Unusual Experiment of Siberian Scientists.” Translated by SCITRAN. Wright-Patterson AFB, Ohio: Foreign Technology Division, September 1987.

Watt, Angus. “Weather Modification: The Ultimate Weapon?” Maxwell AFB, Ala.: Air War College, 1993.

Wei, Zhou. “Meteorological Weapons.” Translated by SCITRAN. Wright-Patterson AFB, Ohio: Foreign Technology Division, March 1985.