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Weather as a Force Multiplier: Owning the Weather in 2025

A Research Paper
Presented To

Air Force *2025*

by

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Disclaimer

2025 is a study designed to comply with a directive from the chief of staff of the Air Force to examine the concepts, capabilities, and technologies the United States will require to remain the dominant air and space force in the future. Presented on 17 June 1996, this report was produced in the Department of Defense school environment of academic freedom and in the interest of advancing concepts related to national defense. The views expressed in this report are those of the authors and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the United States government.

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This publication has been reviewed by security and policy review authorities, is unclassified, and is cleared for public release.

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Executive Summary

In 2025, US aerospace forces can "own the weather" by capitalizing on emerging technologies and focusing development of those technologies to war-fighting applications. Such a capability offers the war fighter tools to shape the battlespace in ways never before possible. It provides opportunities to impact operations across the full spectrum of conflict and is pertinent to all possible futures. The purpose of this paper is to outline a strategy for the use of a future weather-modification system to achieve military objectives rather than to provide a detailed technical road map.

A high-risk, high-reward endeavor, weather-modification offers a dilemma not unlike the splitting of the atom. While some segments of society will always be reluctant to examine controversial issues such as weather-modification, the tremendous military capabilities that could result from this field are ignored at our own peril. From enhancing friendly operations or disrupting those of the enemy via small-scale tailoring of natural weather patterns to complete dominance of global communications and counterspace control, weather-modification offers the war fighter a wide-range of possible options to defeat or coerce an adversary. Some of the potential capabilities a weather-modification system could provide to a war-fighting commander in chief (CINC) are listed in table 1.

Technology advancements in five major areas are necessary for an integrated weather-modification capability: (1) advanced nonlinear modeling techniques, (2) computational capability, (3) information gathering and transmission, (4) a global sensor array, and (5) weather intervention techniques. Some intervention tools exist today and others may be developed and refined in the future.

Table 1

Operational Capabilities Matrix

DEGRADE ENEMY FORCES	ENHANCE FRIENDLY FORCES
Precipitation Enhancement	**Precipitation Avoidance**
- Flood Lines of Communication - Reduce PGM/Recce Effectiveness - Decrease Comfort Level/Morale	- Maintain/Improve LOC - Maintain Visibility - Maintain Comfort Level/Morale
Storm Enhancement	**Storm Modification**
- Deny Operations	- Choose Battlespace Environment
Precipitation Denial	**Space Weather**
- Deny Fresh Water - Induce Drought	- Improve Communication Reliability - Intercept Enemy Transmissions - Revitalize Space Assets
Space Weather	**Fog and Cloud Generation**
- Disrupt Communications/Radar - Disable/Destroy Space Assets	- Increase Concealment
Fog and Cloud Removal	**Fog and Cloud Removal**
- Deny Concealment - Increase Vulnerability to PGM/Recce	- Maintain Airfield Operations - Enhance PGM Effectiveness
Detect Hostile Weather Activities	**Defend against Enemy Capabilities**

Current technologies that will mature over the next 30 years will offer anyone who has the necessary resources the ability to modify weather patterns and their corresponding effects, at least on the local scale. Current demographic, economic, and environmental trends will create global stresses that provide the impetus necessary for many countries or groups to turn this weather-modification ability into a capability.

In the United States, weather-modification will likely become a part of national security policy with both domestic and international applications. Our government will pursue such a policy, depending on its interests, at various levels. These levels could include unilateral actions, participation in a security framework such as NATO, membership in an international organization such as the UN, or participation in a coalition. Assuming that in 2025 our national security strategy includes weather-modification, its use in our national military strategy will naturally follow. Besides the significant benefits an operational capability would provide, another motivation to pursue weather-modification is to deter and counter potential adversaries.

In this paper we show that appropriate application of weather-modification can provide battlespace dominance to a degree never before imagined. In the future, such operations will enhance air and space superiority and provide new options for battlespace shaping and battlespace awareness.[1] "The technology is there, waiting for us to pull it all together;"[2] in 2025 we can "Own the Weather."

Notes

[1] The weather-modification capabilities described in this paper are consistent with the operating environments and missions relevant for aerospace forces in 2025 as defined by AF/LR, a long-range planning office reporting to the CSAF [based on AF/LR PowerPoint briefing "Air and Space Power Framework for Strategy Development (jda-2lr.ppt)]."

[2] General Gordon R. Sullivan, "Moving into the 21st Century: America's Army and Modernization," *Military Review* (July 1993) quoted in Mary Ann Seagraves and Richard Szymber, "Weather a Force Multiplier," *Military Review*, November/December 1995, 75.

Chapter 1

Introduction

Scenario: Imagine that in 2025 the US is fighting a rich, but now consolidated, politically powerful drug cartel in South America. The cartel has purchased hundreds of Russian-and Chinese-built fighters that have successfully thwarted our attempts to attack their production facilities. With their local numerical superiority and interior lines, the cartel is launching more than 10 aircraft for every one of ours. In addition, the cartel is using the French *system probatoire d' observation de la terre* (SPOT) positioning and tracking imagery systems, which in 2025 are capable of transmitting near-real-time, multispectral imagery with 1 meter resolution. The US wishes to engage the enemy on an uneven playing field in order to exploit the full potential of our aircraft and munitions.

Meteorological analysis reveals that equatorial South America typically has afternoon thunderstorms on a daily basis throughout the year. Our intelligence has confirmed that cartel pilots are reluctant to fly in or near thunderstorms. Therefore, our weather force support element (WFSE), which is a part of the commander in chief's (CINC) air operations center (AOC), is tasked to forecast storm paths and trigger or intensify thunderstorm cells over critical target areas that the enemy must defend with their aircraft. Since our aircraft in 2025 have all-weather capability, the thunderstorm threat is minimal to our forces, and we can effectively and decisively control the sky over the target.

The WFSE has the necessary sensor and communication capabilities to observe, detect, and act on weather-modification requirements to support US military objectives. These capabilities are part of an advanced battle area system that supports the war-fighting CINC. In our scenario, the CINC tasks the WFSE to conduct storm intensification and concealment operations. The WFSE models the atmospheric conditions to forecast, with 90 percent confidence, the likelihood of successful modification using airborne cloud generation and seeding.

In 2025, uninhabited aerospace vehicles (UAV) are routinely used for weather-modification operations. By cross-referencing desired attack times with wind and thunderstorm forecasts and the SPOT satellite's projected orbit, the WFSE generates mission profiles for each UAV. The WFSE guides each UAV using near-real-time information from a networked sensor array.

Prior to the attack, which is coordinated with forecasted weather conditions, the UAVs begin cloud generation and seeding operations. UAVs disperse a cirrus shield to deny enemy visual and infrared (IR) surveillance. Simultaneously, microwave heaters create localized scintillation to disrupt active sensing via synthetic aperture radar (SAR) systems such as the commercially available Canadian search and rescue satellite-aided tracking (SARSAT) that will be widely available in 2025. Other cloud seeding operations cause a developing thunderstorm to intensify over the target, severely limiting the enemy's capability to defend. The WFSE monitors the entire operation in real-time and notes the successful completion of another very important but routine weather-modification mission.

This scenario may seem far-fetched, but by 2025 it is within the realm of possibility. The next chapter explores the reasons for weather-modification, defines the scope, and examines trends that will make it possible in the next 30 years.

Chapter 2

Required Capability

Why Would We Want to Mess with the Weather?

According to Gen Gordon Sullivan, former Army chief of staff, "As we leap technology into the 21st century, we will be able to see the enemy day or night, in any weather— and go after him relentlessly."[1] A global, precise, real-time, robust, systematic weather-modification capability would provide war-fighting CINCs with a powerful force multiplier to achieve military objectives. Since weather will be common to all possible futures, a weather-modification capability would be universally applicable and have utility across the entire spectrum of conflict. The capability of influencing the weather even on a small scale could change it from a force degrader to a force multiplier.

People have always wanted to be able to do something about the weather. In the US, as early as 1839, newspaper archives tell of people with serious and creative ideas on how to make rain.[2] In 1957, the president's advisory committee on weather control explicitly recognized the military potential of weather-modification, warning in their report that it could become a more important weapon than the atom bomb.[3]

However, controversy since 1947 concerning the possible legal consequences arising from the deliberate alteration of large storm systems meant that little future experimentation could be conducted on storms which had the potential to reach land.[4] In 1977, the UN General Assembly adopted a resolution prohibiting the hostile use of environmental modification techniques. The resulting "Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Technique (ENMOD)" committed the signatories to refrain from any military or other hostile use of weather-modification which could result in widespread, long-lasting, or severe effects.[5] While these two events have not halted the pursuit of weather-modification research, they have significantly inhibited its pace and the development of associated technologies, while producing a primary focus on suppressive versus intensification activities.

The influence of the weather on military operations has long been recognized. During World War II, Eisenhower said,

> [i]n Europe bad weather is the worst enemy of the air [operations]. Some soldier once said, "The weather is always neutral." Nothing could be more untrue. Bad weather is obviously the enemy of the side that seeks to launch projects requiring good weather, or of the side possessing great assets, such as strong air forces, which depend upon good weather for effective operations. If really bad weather should endure permanently, the Nazi would need nothing else to defend the Normandy coast![6]

The impact of weather has also been important in more recent military operations. A significant number of the air sorties into Tuzla during the initial deployment supporting the Bosnian peace operation aborted due to weather. During Operation Desert Storm, Gen Buster C. Glosson asked his weather officer to tell him which targets would be clear in 48 hours for inclusion in the air tasking order (ATO).[7] But current forecasting capability is only 85 percent accurate for no more than 24 hours, which doesn't adequately meet the needs of the ATO planning cycle. Over 50 percent of the F-117 sorties weather aborted over their targets and A-10s only flew 75 of 200 scheduled close air support (CAS) missions due to low cloud cover during the first two days of the campaign.[8] The application of weather-modification technology to clear a hole over the targets long enough for F-117s to attack and place bombs on target or clear the fog from the runway at Tuzla would have been a very effective force multiplier. Weather-modification clearly has potential for military use at the operational level to reduce the elements of fog and friction for friendly operations and to significantly increase them for the enemy.

What Do We Mean by "Weather-modification"?

Today, weather-modification is the alteration of weather phenomena over a limited area for a limited period of time.[9] Within the next three decades, the concept of weather-modification could expand to include the ability to shape weather patterns by influencing their determining factors.[10] Achieving such a highly accurate and reasonably precise weather-modification capability in the next 30 years will require overcoming some challenging but not insurmountable technological and legal hurdles.

Technologically, we must have a solid understanding of the variables that affect weather. We must be able to model the dynamics of their relationships, map the possible results of their interactions, measure their actual real-time values, and influence their values to achieve a desired outcome. Society will have to provide the resources and legal basis for a mature capability to develop. How could all of this happen? The following notional scenario postulates how weather-modification might become both technically feasible and socially desirable by 2025.

Between now and 2005, technological advances in meteorology and the demand for more precise weather information by global businesses will lead to the successful identification and parameterization of the major variables that affect weather. By 2015, advances in computational capability, modeling techniques, and atmospheric information tracking will produce a highly accurate and reliable weather prediction capability, validated against real-world weather. In the following decade, population densities put pressure on the worldwide availability and cost of food and usable water. Massive life and property losses associated with natural weather disasters become increasingly unacceptable. These pressures prompt governments and/or other organizations who are able to capitalize on the technological advances of the previous 20 years to pursue a highly accurate and reasonably precise weather-modification capability. The increasing urgency to realize the benefits of this capability stimulates laws and treaties, and some unilateral actions, making the risks required to validate and refine it acceptable. By 2025, the world, or parts of it, are able to shape local weather patterns by influencing the factors that affect climate, precipitation, storms and their effects, fog, and near space. These highly accurate and reasonably precise civil applications of weather-modification technology have obvious military implications. This is particularly true for aerospace forces, for while weather may affect all mediums of operation, it operates in ours.

The term weather-modification may have negative connotations for many people, civilians and military members alike. It is thus important to define the scope to be considered in this paper so that potential critics or proponents of further research have a common basis for discussion.

In the broadest sense, weather-modification can be divided into two major categories: suppression and intensification of weather patterns. In extreme cases, it might involve the creation of completely new weather patterns, attenuation or control of severe storms, or even alteration of global climate on a far-reaching and/or long-lasting scale. In the mildest and least controversial cases it may consist of inducing or suppressing precipitation, clouds, or fog for short times over a small-scale region. Other low-intensity applications might include the alteration and/or use of near space as a medium to enhance communications, disrupt active or passive sensing, or other purposes. In conducting the research for this study, the broadest possible interpretation of weather-modification was initially embraced, so that the widest range of opportunities available for our military in 2025 were thoughtfully considered. However, for several reasons described below, this paper focuses primarily on localized and short-term forms of weather-modification and how these could be incorporated into war-fighting capability. The primary areas discussed include generation and dissipation of precipitation, clouds, and fog; modification of localized storm systems; and the use of the ionosphere and near space for space control and communications dominance. These applications are consistent with CJCSI 3810.01, *"Meteorological and Oceanographic Operations."*[11]

Extreme and controversial examples of weather modification—creation of made-to-order weather, large-scale climate modification, creation and/or control (or "steering") of severe storms, etc.—were researched as part of this study but receive only brief mention here because, in the authors' judgment, the technical obstacles preventing their application appear insurmountable within 30 years.[12] If this were not the case, such applications would have been included in this report as potential military options, despite their controversial and potentially malevolent nature and their inconsistency with standing UN agreements to which the US is a signatory.

On the other hand, the weather-modification applications proposed in this report range from technically proven to potentially feasible. They are similar, however, in that none are currently employed or envisioned for employment by our operational forces. They are also similar in their potential value for the war fighter of the future, as we hope to convey in the following chapters. A notional integrated system that incorporates weather-modification tools will be described in the next chapter; how those tools might be applied are then discussed within the framework of the Concept of Operations in chapter 4.

[1] Gen Gordon R. Sullivan, "Moving into the 21st Century: America's Army and Modernization," *Military Review* (July 1993) quoted in Mary Ann Seagraves and Richard Szymber, "Weather a Force Multiplier," *Military Review*, November/December 1995, 75.

[2] Horace R. Byers, "History of Weather-modification," in Wilmot N. Hess, ed. *Weather and Climate Modification*, (New York: John Wiley & Sons, 1974), 4.

[3] William B. Meyer, "The Life and Times of US Weather: What Can We Do About It?" *American Heritage* 37, no. 4 (June/July 1986), 48.

[4] Byers, 13.

[5] US Department of State, *The Department of State Bulletin.* 74, no. 1981 (13 June 1977): 10.

[6] Dwight D Eisenhower. "Crusade in Europe," quoted in John F. Fuller, Thor's Legions (Boston: American Meterology Society, 1990), 67.

[7] Interview of Lt Col Gerald F. Riley, Staff Weather Officer to CENTCOM OIC of CENTAF Weather Support Force and Commander of 3rd Weather Squadron, in "Desert Shield/Desert Storm Interview Series," by Dr William E. Narwyn, AWS Historian, 29 May 1991.

[8] Thomas A. Keaney and Eliot A. Cohen. *Gulf War Air Power Survey Summary Report* (Washington D.C.: Government Printing Office, 1993), 172.

[9] Herbert S. Appleman, *An Introduction to Weather-modification* (Scott AFB, Ill.: Air Weather Service/MAC, September 1969), 1.

[10] William Bown, "Mathematicians Learn How to Tame Chaos," *New Scientist*, 30 May 1992, 16.

[11] CJCSI 3810.01, *Meteorological and Oceanographic Operations*, 10 January 95. This CJCS Instruction establishes policy and assigns responsibilities for conducting meteorological and oceanographic operations. It also defines the terms widespread, long-lasting, and severe, in order to identify those activities that US forces are prohibited from conducting under the terms of the UN Environmental Modification Convention. Widespread is defined as encompassing an area on the scale of several hundred km; long-lasting means lasting for a period of months, or approximately a season; and severe involves serious or significant disruption or harm to human life, natural and economic resources, or other assets.

[12] Concern about the unintended consequences of attempting to "control" the weather is well justified. Weather is a classic example of a chaotic system (i.e., a system that never exactly repeats itself). A chaotic system is also extremely sensitive: minuscule differences in conditions greatly affect outcomes. According to Dr. Glenn James, a widely published chaos expert, technical advances may provide a means to predict *when* weather transitions will occur and the magnitude of the inputs required to cause those transitions; however, it will never be possible to precisely predict changes that occur as a result of our inputs. The chaotic nature of weather also limits our ability to make accurate long-range forecasts. The renowned physicist Edward Teller recently presented calculations he performed to determine the long-range weather forecasting improvement that would result from a satellite constellation providing continuous atmospheric measurements over a 1 km^2 grid worldwide. Such a system, which is currently cost-prohibitive, would only improve long-range forecasts from the current five days to approximately 14 days. Clearly, there are definite physical limits to mankind's ability to control nature, but the extent of those physical limits remains an open question. Sources: G. E. James, "Chaos Theory: The Essentials for Military Applications," in *ACSC Theater Air Campaign Studies Coursebook*, AY96, 8 (Maxwell AFB, Ala: Air University Press, 1995), 1-64. The Teller calculations are cited in Reference 49 of this source.

Chapter 3

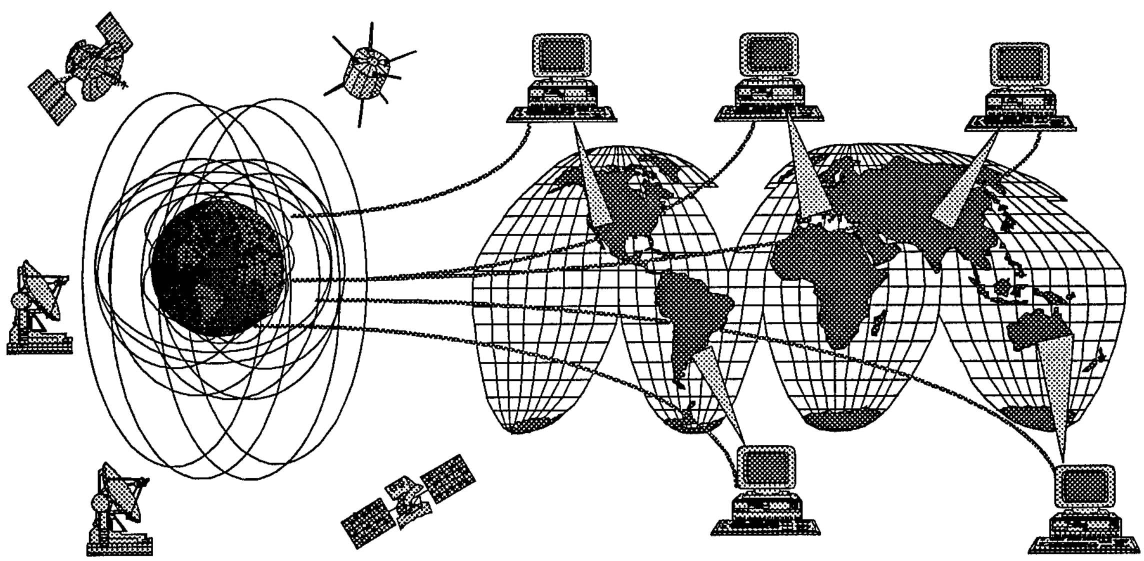
System Description

Our vision is that by 2025 the military could influence the weather on a mesoscale (<200 km^2) or microscale (immediate local area) to achieve operational capabilities such as those listed in Table 1. The capability would be the synergistic result of a system consisting of (1) highly trained weather force specialists (WFS) who are members of the CINC's weather force support element (WFSE); (2) access ports to the global weather network (GWN), where worldwide weather observations and forecasts are obtained near-real-time from civilian and military sources; (3) a dense, highly accurate local area weather sensing and communication system; (4) an advanced computer local area weather-modification modeling and prediction capability within the area of responsibility (AOR); (5) proven weather-modification intervention technologies; and (6) a feedback capability.

The Global Weather Network

The GWN is envisioned to be an evolutionary expansion of the current military and civilian worldwide weather data network. By 2025, it will be a super high-speed, expanded bandwidth, communication network filled with near-real-time weather observations taken from a denser and more accurate worldwide observation network resulting from highly improved ground, air, maritime, and space sensors. The network will also provide access to forecast centers around the world where sophisticated, tailored forecast and data products, generated from weather prediction models (global, regional, local, specialized, etc.) based on the latest nonlinear mathematical techniques are made available to GWN customers for near-real-time use.

By 2025, we envision that weather prediction models, in general, and mesoscale weather-modification models, in particular, will be able to emulate all-weather producing variables, along with their interrelated dynamics, and prove to be highly accurate in stringent measurement trials against empirical data. The brains of these models will be advanced software and hardware capabilities which can rapidly ingest trillions of environmental data points, merge them into usable data bases, process the data through the weather prediction models, and disseminate the weather information over the GWN in near-real-time.[1] This network is depicted schematically in figure 3-1.



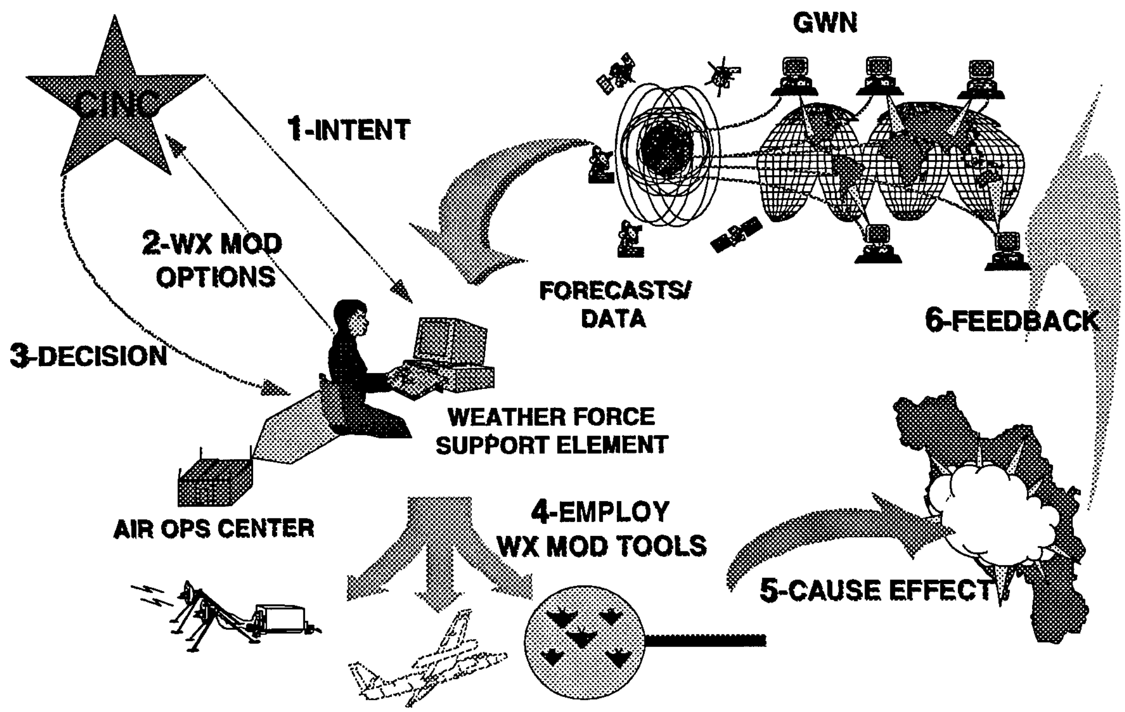
Source: Microsoft Clipart Gallery © 1995 with courtesy from Microsoft.

Figure 3-1. Global Weather Network

Evidence of the evolving future weather modeling and prediction capability as well as the GWN can be seen in the national oceanic and atmospheric administration's (NOAA) 1995–2005 strategic plan. It includes program elements to "advance short-term warning and forecast services, implement seasonal to inter-annual climate forecasts, and predict and assess decadal to centennial change;"[2] it does not, however, include plans for weather-modification modeling or modification technology development. NOAA's plans include extensive data gathering programs such as Next Generation Radar (NEXRAD) and Doppler weather surveillance systems deployed throughout the US. Data from these sensing systems feed into over 100 forecast centers for processing by the Advanced Weather Interactive Processing System (AWIPS), which will provide data communication, processing, and display capabilities for extensive forecasting. In addition, NOAA has leased a Cray C90 supercomputer capable of performing over 1.5×10^{10} operations per second that has already been used to run a Hurricane Prediction System.[3]

Applying Weather-modification to Military Operations

How will the military, in general, and the USAF, in particular, manage and employ a weather-modification capability? We envision this will be done by the weather force support element (WFSE), whose primary mission would be to support the war-fighting CINCs with weather-modification options, in addition to current forecasting support. Although the WFSE could operate anywhere as long as it has access to the GWN and the system components already discussed, it will more than likely be a component within the AOC or its 2025-equivalent. With the CINC's intent as guidance, the WFSE formulates weather-modification options using information provided by the GWN, local weather data network, and weather-modification forecast model. The options include range of effect, probability of success, resources to be expended, the enemy's vulnerability, and risks involved. The CINC chooses an effect based on these inputs, and the WFSE then implements the chosen course, selecting the right modification tools and employing them to achieve the desired effect. Sensors detect the change and feed data on the new weather pattern to the modeling system which updates its forecast accordingly. The WFSE checks the effectiveness of its efforts by pulling down the updated current conditions and new forecast(s) from the GWN and local weather data network, and plans follow-on missions as needed. This concept is illustrated in figure 3-2.



Source: Microsoft Clipart Gallery © 1995 with courtesy from Microsoft.

Figure 3-2. The Military System for Weather-Modification Operations.

WFSE personnel will need to be experts in information systems and well schooled in the arts of both offensive and defensive information warfare. They would also have an in-depth understanding of the GWN and an appreciation for how weather-modification could be employed to meet a CINC's needs.

Because of the nodal web nature of the GWN, this concept would be very flexible. For instance, a WFSE could be assigned to each theater to provide direct support to the CINC. The system would also be survivable, with multiple nodes connected to the GWN.

A product of the information age, this system would be most vulnerable to information warfare. Each WFSE would need the most current defensive and offensive information capabilities available. Defensive abilities would be necessary for survival. Offensive abilities could provide spoofing options to create virtual weather in the enemy's sensory and information systems, making it more likely for them to make decisions producing results of our choosing rather than theirs. It would also allow for the capability to mask or disguise our weather-modification activities.

Two key technologies are necessary to meld an integrated, comprehensive, responsive, precise, and effective weather-modification system. Advances in the science of chaos are critical to this endeavor. Also key to the feasibility of such a system is the ability to model the extremely complex nonlinear system of global weather in ways that can accurately predict the outcome of changes in the influencing variables. Researchers have already successfully controlled single variable nonlinear systems in the lab and hypothesize that current mathematical techniques and computer capacity could handle systems with up to five variables. Advances in these two areas would make it feasible to affect regional weather patterns by making small, continuous nudges to one or more influencing factors. Conceivably, with enough lead time and the right conditions, you could get "made-to-order" weather.[4]

Developing a true weather-modification capability will require various intervention tools to adjust the appropriate meteorological parameters in predictable ways. It is this area that must be developed by the military based on specific required capabilities such as those listed in table 1, table 1 is located in the Executive Summary. Such a system would contain a sensor array and localized battle area data net to provide the fine level of resolution required to detect intervention effects and provide feedback. This net would include ground, air, maritime, and space sensors as well as human observations in order to ensure the reliability and responsiveness of the system, even in the event of enemy countermeasures. It would also include specific intervention tools and technologies, some of which already exist and others which must be developed. Some of these proposed tools are described in the following chapter titled Concept of Operations. The total weather-modification process would be a real-time loop of continuous, appropriate, measured interventions, and feedback capable of producing desired weather behavior.

Notes

[1] SPACECAST 2020, *Space Weather Support for Communications*, white paper G (Maxwell AFB, Ala.: Air War College/2020, 1994).

[2] Rear Adm Sigmund Petersen, "NOAA Moves Toward The 21st Century," *The Military Engineer* 20, no. 571 (June-July 1995): 44.

[3] Ibid.

[4] William Brown, "Mathematicians Learn How to Tame Chaos," *New Scientist* (30 May 1992): 16.

Chapter 4

Concept of Operations

The essential ingredient of the weather-modification system is the set of intervention techniques used to modify the weather. The number of specific intervention methodologies is limited only by the imagination, but with few exceptions they involve infusing either energy or chemicals into the meteorological process in the right way, at the right place and time. The intervention could be designed to modify the weather in a number of ways, such as influencing clouds and precipitation, storm intensity, climate, space, or fog.

Precipitation

For centuries man has desired the ability to influence precipitation at the time and place of his choosing. Until recently, success in achieving this goal has been minimal; however, a new window of opportunity may exist resulting from development of new technologies and an increasing world interest in relieving water shortages through precipitation enhancement. Consequently, we advocate that the DOD explore the many opportunities (and also the ramifications) resulting from development of a capability to influence precipitation or conducting "selective precipitation modification." Although the capability to influence precipitation over the long term (i.e., for more than several days) is still not fully understood. By 2025 we will certainly be capable of increasing or decreasing precipitation over the short term in a localized area.

Before discussing research in this area, it is important to describe the benefits of such a capability. While many military operations may be influenced by precipitation, ground mobility is most affected. Influencing precipitation could prove useful in two ways. First, enhancing precipitation could decrease the enemy's trafficability by muddying terrain, while also affecting their morale. Second, suppressing precipitation could increase friendly trafficability by drying out an otherwise muddied area.

What is the possibility of developing this capability and applying it to tactical operations by 2025? Closer than one might think. Research has been conducted in precipitation modification for many years, and an aspect of the resulting technology was applied to operations during the Vietnam War.[1] These initial attempts provide a foundation for further development of a true capability for selective precipitation modification.

Interestingly enough, the US government made a conscious decision to stop building upon this foundation. As mentioned earlier, international agreements have prevented the US from investigating weather-modification operations that could have widespread, long-lasting, or severe effects. However, possibilities do exist (within the boundaries of established treaties) for using localized precipitation modification over the short term, with limited and potentially positive results.

These possibilities date back to our own previous experimentation with precipitation modification. As stated in an article appearing in the *Journal of Applied Meteorology*,

> [n]early all the weather-modification efforts over the last quarter century have been aimed at producing changes on the cloud scale through exploitation of the saturated vapor pressure difference between ice and water. This is not to be criticized but it is time we also consider the feasibility of weather-modification on other time-space scales and with other physical hypotheses.[2]

This study by William M. Gray, et al., investigated the hypothesis that "significant beneficial influences can be derived through judicious exploitation of the solar absorption potential of carbon black dust."[3] The study ultimately found that this technology could be used to enhance rainfall on the mesoscale, generate cirrus clouds, and enhance cumulonimbus (thunderstorm) clouds in otherwise dry areas.

The technology can be described as follows. Just as a black tar roof easily absorbs solar energy and subsequently radiates heat during a sunny day, carbon black also readily absorbs solar energy. When dispersed in microscopic or "dust" form in the air over a large body of water, the carbon becomes hot and heats the surrounding air, thereby increasing the amount of evaporation from the body of water below. As the surrounding air heats up, parcels of air will rise and the water vapor contained in the rising air parcel will eventually condense to form clouds. Over time the cloud droplets increase in size as more and more water vapor condenses, and eventually they become too large and heavy to stay suspended and will fall as rain or other forms of precipitation.[4] The study points out that this precipitation enhancement technology would work best "upwind from coastlines with onshore flow." Lake-effect snow along the southern edge of the Great Lakes is a naturally occurring phenomenon based on similar dynamics.

Can this type of precipitation enhancement technology have military applications? Yes, if the right conditions exist. For example, if we are fortunate enough to have a fairly large body of water available upwind from the targeted battlefield, carbon dust could be placed in the atmosphere over that water. Assuming the dynamics are supportive in the atmosphere, the rising saturated air will eventually form clouds and rainshowers downwind over the land.[5] While the likelihood of having a body of water located upwind of the battlefield is unpredictable, the technology could prove enormously useful under the right conditions. Only further experimentation will determine to what degree precipitation enhancement can be controlled.

If precipitation enhancement techniques are successfully developed and the right natural conditions also exist, we must also be able to disperse carbon dust into the desired location. Transporting it in a completely controlled, safe, cost-effective, and reliable manner requires innovation. Numerous dispersal techniques have already been studied, but the most convenient, safe, and cost-effective method discussed is the use of afterburner-type jet engines to generate carbon particles while flying through the targeted air. This method is based on injection of liquid hydrocarbon fuel into the afterburner's combustion gases. This direct generation method was found to be more desirable than another plausible method (i.e., the transport of large quantities of previously produced and properly sized carbon dust to the desired altitude).

The carbon dust study demonstrated that small-scale precipitation enhancement is possible and has been successfully verified under certain atmospheric conditions. Since the study was conducted, no known military applications of this technology have been realized. However, we can postulate how this technology might be used in the future by examining some of the delivery platforms conceivably available for effective dispersal of carbon dust or other effective modification agents in the year 2025.

One method we propose would further maximize the technology's safety and reliability, by virtually eliminating the human element. To date, much work has been done on UAVs which can closely (if not completely) match the capabilities of piloted aircraft. If this UAV technology were combined with stealth and carbon dust technologies, the result could be a UAV aircraft invisible to radar while en route to the targeted area, which could spontaneously create carbon dust in any location. However, minimizing the number of

UAVs required to complete the mission would depend upon the development of a new and more efficient system to produce carbon dust by a follow-on technology to the afterburner-type jet engines previously mentioned. In order to effectively use stealth technology, this system must also have the ability to disperse carbon dust while minimizing (or eliminating) the UAV's infrared heat source.

In addition to using stealth UAV and carbon dust absorption technology for precipitation enhancement, this delivery method could also be used for precipitation suppression. Although the previously mentioned study did not significantly explore the possibility of cloud seeding for precipitation suppression, this possibility does exist. If clouds were seeded (using chemical nuclei similar to those used today or perhaps a more effective agent discovered through continued research) before their downwind arrival to a desired location, the result could be a suppression of precipitation. In other words, precipitation could be "forced" to fall before its arrival in the desired territory, thereby making the desired territory "dry." The strategic and operational benefits of doing this have previously been discussed.

Fog

In general, successful fog dissipation requires some type of heating or seeding process. Which technique works best depends on the type of fog encountered. In simplest terms, there are two basic types of fog—cold and warm. Cold fog occurs at temperatures below 32°F. The best-known dissipation technique for cold fog is to seed it from the air with agents that promote the growth of ice crystals.[6]

Warm fog occurs at temperatures above 32°F and accounts for 90 percent of the fog-related problems encountered by flight operations.[7] The best-known dissipation technique is heating because a small temperature increase is usually sufficient to evaporate the fog. Since heating usually isn't practical, the next most effective technique is hygroscopic seeding.[8] Hygroscopic seeding uses agents that absorb water vapor. This technique is most effective when accomplished from the air but can also be accomplished from the ground.[9] Optimal results require advance information on fog depth, liquid water content, and wind.[10]

Decades of research show that fog dissipation is an effective application of weather-modification technology with demonstrated savings of huge proportions for both military and civil aviation.[11] Local municipalities have also shown an interest in applying these techniques to improve the safety of high-speed highways transiting areas of frequently occurring dense fog.[12]

There are some emerging technologies which may have important applications for fog dispersal. As discussed earlier, heating is the most effective dispersal method for the most commonly occurring type of fog. Unfortunately, it has proved impractical for most situations and would be difficult at best for contingency operations. However, the development of directed radiant energy technologies, such as microwaves and lasers, could provide new possibilities.

Lab experiments have shown microwaves to be effective for the heat dissipation of fog. However, results also indicate that the energy levels required exceed the US large power density exposure limit of 100 watt/m^2 and would be very expensive.[13] Field experiments with lasers have demonstrated the capability to dissipate warm fog at an airfield with zero visibility. Generating 1 watt/cm^2, which is approximately the US large power density exposure limit, the system raised visibility to one quarter of a mile in 20 seconds.[14] Laser systems described in the Space Operations portion of this AF 2025 study could certainly provide this capability as one of their many possible uses.

With regard to seeding techniques, improvements in the materials and delivery methods are not only plausible but likely. Smart materials based on nanotechnology are currently being developed with gigaops computer capability at their core. They could adjust their size to optimal dimensions for a given fog seeding situation and even make adjustments throughout the process. They might also enhance their dispersal qualities by adjusting their buoyancy, by communicating with each other, and by steering themselves within the fog. They will be able to provide immediate and continuous effectiveness feedback by integrating with a larger sensor network and can also change their temperature and polarity to improve their seeding effects.[15] As mentioned above, UAVs could be used to deliver and distribute these smart materials.

Recent army research lab experiments have demonstrated the feasibility of generating fog. They used commercial equipment to generate thick fog in an area 100 meters long. Further study has shown fogs to be effective at blocking much of the UV/IR/visible spectrum, effectively masking emitters of such radiation from IR weapons.[16] This technology would enable a small military unit to avoid detection in the IR spectrum. Fog could be generated to quickly, conceal the movement of tanks or infantry, or it could conceal military operations, facilities, or equipment. Such systems may also be useful in inhibiting observations of sensitive rear-area operations by electro-optical reconnaissance platforms.[17]

Storms

The desirability to modify storms to support military objectives is the most aggressive and controversial type of weather-modification. The damage caused by storms is indeed horrendous. For instance, a tropical storm has an energy equal to 10,000 one-megaton hydrogen bombs,[18] and in 1992 Hurricane Andrew totally destroyed Homestead AFB, Florida, caused the evacuation of most military aircraft in the southeastern US, and resulted in $15.5 billion of damage.[19] However, as one would expect based on a storm's energy level, current scientific literature indicates that there are definite physical limits on mankind's ability to modify storm systems. By taking this into account along with political, environmental, economic, legal, and moral considerations, we will confine our analysis of storms to localized thunderstorms and thus do not consider major storm systems such as hurricanes or intense low-pressure systems.

At any instant there are approximately 2,000 thunderstorms taking place. In fact 45,000 thunderstorms, which contain heavy rain, hail, microbursts, wind shear, and lightning form daily.[20] Anyone who has flown frequently on commercial aircraft has probably noticed the extremes that pilots will go to avoid thunderstorms. The danger of thunderstorms was clearly shown in August 1985 when a jumbo jet crashed killing 137 people after encountering microburst wind shears during a rain squall.[21] These forces of nature impact all aircraft and even the most advanced fighters of 1996 make every attempt to avoid a thunderstorm.

Will bad weather remain an aviation hazard in 2025? The answer, unfortunately, is "yes," but projected advances in technology over the next 30 years will diminish the hazard potential. Computer-controlled flight systems will be able to "autopilot" aircraft through rapidly changing winds. Aircraft will also have highly accurate, onboard sensing systems that can instantaneously "map" and automatically guide the aircraft through the safest portion of a storm cell. Aircraft are envisioned to have hardened electronics that can withstand the effects of lightning strikes and may also have the capability to generate a surrounding electropotential field that will neutralize or repel lightning strikes.

Assuming that the US achieves some or all of the above outlined aircraft technical advances and maintains the technological "weather edge" over its potential adversaries, we can next look at how we could modify the battlespace weather to make the best use of our technical advantage.

Weather-modification technologies might involve techniques that would increase latent heat release in the atmosphere, provide additional water vapor for cloud cell development, and provide additional surface and lower atmospheric heating to increase atmospheric instability. Critical to the success of any attempt to trigger a storm cell is the pre-existing atmospheric conditions locally and regionally. The atmosphere must already be conditionally unstable and the large-scale dynamics must be supportive of vertical cloud development. The focus of the weather-modification effort would be to provide additional "conditions" that would make the atmosphere unstable enough to generate cloud and eventually storm cell development. The path of storm cells once developed or enhanced is dependent not only on the mesoscale dynamics of the storm but the regional and synoptic (global) scale atmospheric wind flow patterns in the area which are currently not subject to human control.

As indicated, the technical hurdles for storm development in support of military operations are obviously greater than enhancing precipitation or dispersing fog as described earlier. One area of storm research that would significantly benefit military operations is lightning modification. Most research efforts are being conducted to develop techniques to lessen the occurrence or hazards associated with lightning. This is important research for military operations and resource protection, but some offensive military benefit could be obtained by doing research on increasing the potential and intensity of lightning. Concepts to explore include increasing the basic efficiency of the thunderstorm, stimulating the triggering mechanism that initiates the bolt, and triggering lightning such as that which struck Apollo 12 in 1968.[22] Possible mechanisms to investigate would be ways to modify the electropotential characteristics over certain targets to induce lightning strikes on the desired targets as the storm passes over their location.

In summary, the ability to modify battlespace weather through storm cell triggering or enhancement would allow us to exploit the technological "weather" advances of our 2025 aircraft; this area has tremendous potential and should be addressed by future research and concept development programs.

Exploitation of "NearSpace" for Space Control

This section discusses opportunities for control and modification of the ionosphere and near-space environment for force enhancement; specifically to enhance our own communications, sensing, and navigation capabilities and/or impair those of our enemy. A brief technical description of the ionosphere and its importance in current communications systems is provided in appendix A.

By 2025, it may be possible to modify the ionosphere and near space, creating a variety of potential applications, as discussed below. However, before ionospheric modification becomes possible, a number of evolutionary advances in space weather forecasting and observation are needed. Many of these needs were described in a Spacecast 2020 study, Space Weather Support for Communications.[23] Some of the suggestions from this study are included in appendix B; it is important to note that our ability to exploit near space via active modification is dependent on successfully achieving reliable observation and prediction capabilities.

Opportunities Afforded by Space Weather-modification

Modification of the near-space environment is crucial to battlespace dominance. General Charles Horner, former commander in chief, United States space command, described his worst nightmare as "seeing an entire Marine battalion wiped out on some foreign landing zone because he was unable to deny the enemy intelligence and imagery generated from space."[24] Active modification could provide a "technological fix" to jam the enemy's active and passive surveillance and reconnaissance systems. In short, *an operational capability to modify the near-space environment would ensure space superiority in 2025; this capability would allow us to shape and control the battlespace via enhanced communication, sensing, navigation, and precision engagement systems.*

While we recognize that technological advances may negate the importance of certain electromagnetic frequencies for US aerospace forces in 2025 (such as radio frequency (RF), high-frequency (HF) and very high-frequency (VHF) bands), the capabilities described below are nevertheless relevant. Our nonpeer adversaries will most likely still depend on such frequencies for communications, sensing, and navigation and would thus be extremely vulnerable to disruption via space weather-modification.

Communications Dominance via Ionospheric Modification

Modification of the ionosphere to enhance or disrupt communications has recently become the subject of active research. According to Lewis M. Duncan, and Robert L. Showen, the Former Soviet Union (FSU) conducted theoretical and experimental research in this area at a level considerably greater than comparable programs in the West.[25] There is a strong motivation for this research, because

> induced ionospheric modifications may influence, or even disrupt, the operation of radio systems relying on propagation through the modified region. The controlled generation or accelerated dissipation of ionospheric disturbances may be used to produce new propagation paths, otherwise unavailable, appropriate for selected RF missions.[26]

A number of methods have been explored or proposed to modify the ionosphere, including injection of chemical vapors and heating or charging via electromagnetic radiation or particle beams (such as ions, neutral particles, x-rays, MeV particles, and energetic electrons).[27] It is important to note that many techniques to modify the upper atmosphere have been successfully demonstrated experimentally. Ground-based modification techniques employed by the FSU include vertical HF heating, oblique HF heating, microwave heating, and magnetospheric modification.[28] Significant military applications of such operations include low frequency (LF) communication production, HF ducted communications, and creation of an artificial ionosphere (discussed in detail below). Moreover, developing countries also recognize the benefit of ionospheric modification: "in the early 1980's, Brazil conducted an experiment to modify the ionosphere by chemical injection."[29]

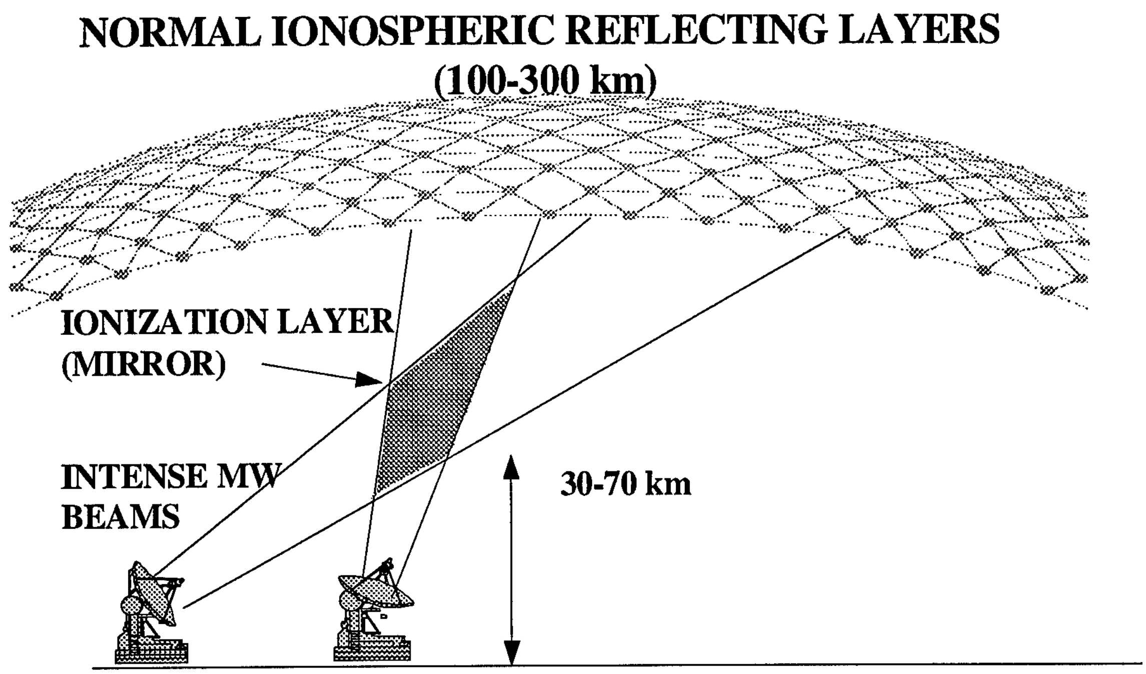
Several high-payoff capabilities that could result from the modification of the ionosphere or near space are described briefly below. It should be emphasized that this list is not comprehensive; modification of the ionosphere is an area rich with potential applications and there are also likely spin-off applications that have yet to be envisioned.

Ionospheric mirrors for pinpoint communication or over-the-horizon (OTH) radar transmission. The properties and limitations of the ionosphere as a reflecting medium for high-frequency radiation are described in appendix A. The major disadvantage in depending on the ionosphere to reflect radio waves is its variability, which is due to normal space weather and events such as solar flares and geomagnetic storms. The ionosphere has been described as a crinkled sheet of wax paper whose relative position rises and sinks depending on weather conditions. The surface topography of the crinkled paper also constantly changes, leading to variability in its reflective, refractive, and transmissive properties.

Creation of an artificial uniform ionosphere was first proposed by Soviet researcher A. V. Gurevich in the mid-1970s. An artificial ionospheric mirror (AIM) would serve as a precise mirror for electromagnetic radiation of a selected frequency or a range of frequencies. It would thereby be useful for both pinpoint control of friendly communications and interception of enemy transmissions.

This concept has been described in detail by Paul A. Kossey, et al. in a paper entitled "Artificial Ionospheric Mirrors (AIM)."[30] The authors describe how one could precisely control the location and height of the region of artificially produced ionization using crossed microwave (MW) beams, which produce atmospheric breakdown (ionization) of neutral species. The implications of such control are enormous: one would no longer be subject to the vagaries of the natural ionosphere but would instead have direct control of the propagation environment. Ideally, the AIM could be rapidly created and then would be maintained only for a brief operational period. A schematic depicting the crossed-beam approach for generation of an AIM is shown in figure 4-1.[31]

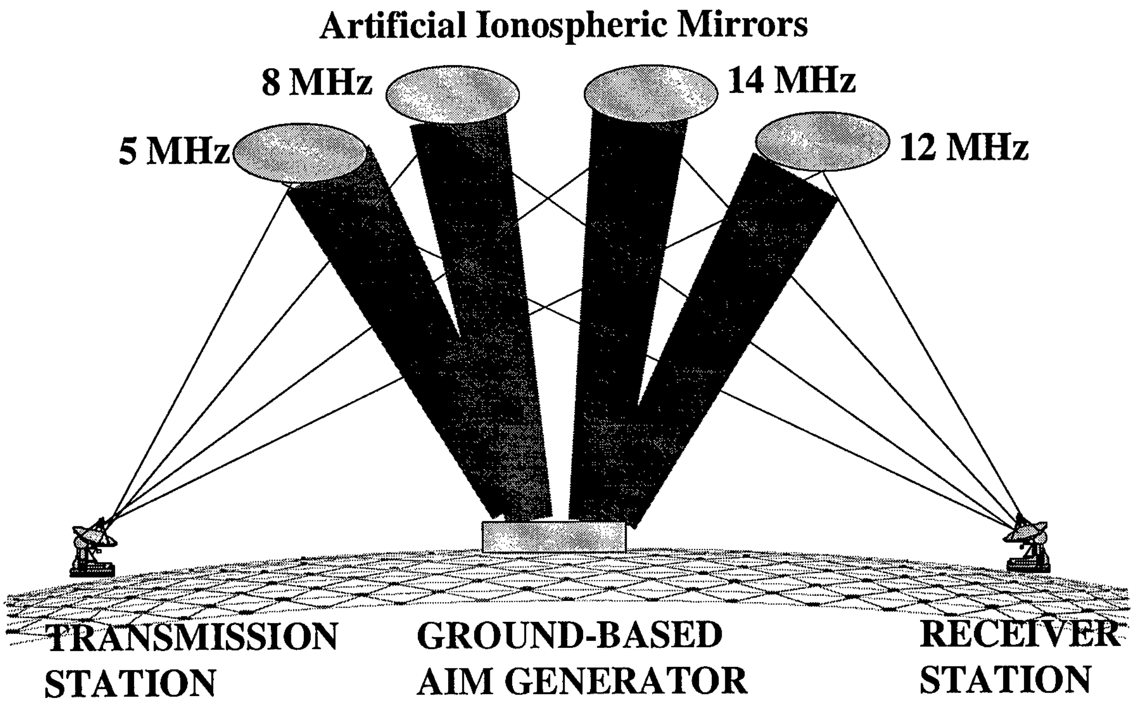
An AIM could theoretically reflect radio waves with frequencies up to 2 GHz, which is nearly two orders of magnitude higher than those waves reflected by the natural ionosphere. The MW radiator power requirements for such a system are roughly an order of magnitude greater than 1992 state-of-the-art systems; however, by 2025 such a power capability is expected to be easily achievable.



Source: Microsoft Clipart Gallery © 1995 with courtesy from Microsoft.

Figure 4-1. Crossed-Beam Approach for Generating an Artificial Ionospheric Mirror

Besides providing pinpoint communication control and potential interception capability, this technology would also provide communication capability at specified frequencies, as desired. Figure 4-2 shows how a ground-based radiator might generate a series of AIMs, each of which would be tailored to reflect a selected transmission frequency. Such an arrangement would greatly expand the available bandwidth for communications and also eliminate the problem of interference and crosstalk (by allowing one to use the requisite power level).



Source: Microsoft Clipart Gallery © 1995 with courtesy from Microsoft.

Figure 4-2. Artificial Ionospheric Mirrors Point-to-Point Communications

Kossey et al. also describe how AIMs could be used to improve the capability of OTH radar:

> AIM based radar could be operated at a frequency chosen to optimize target detection, rather than be limited by prevailing ionospheric conditions. This, combined with the possibility of controlling the radar's wave polarization to mitigate clutter effects, could result in reliable detection of cruise missiles and other low observable targets.[32]

A schematic depicting this concept is shown in figure 4-3. Potential advantages over conventional OTH radars include frequency control, mitigation of auroral effects, short range operation, and detection of a smaller cross-section target.

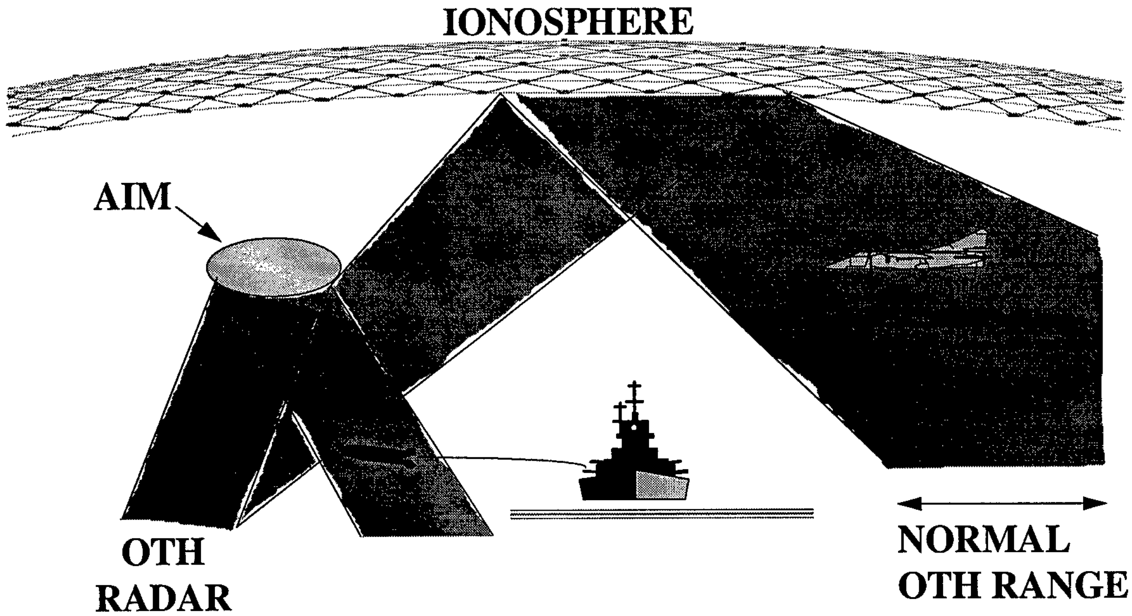


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Figure 4-3. Artificial Ionospheric Mirror Over-the-Horizon Surveillance Concept.

Disruption of communications and radar via ionospheric control. A variation of the capability proposed above is ionospheric modification to disrupt an enemy's communication or radar transmissions. Because HF communications are controlled directly by the ionosphere's properties, an artificially created ionization region could conceivably disrupt an enemy's electromagnetic transmissions. Even in the absence of an artificial ionization patch, high-frequency modification produces large-scale ionospheric variations which alter HF propagation characteristics. The payoff of research aimed at understanding how to control these variations could be high as both HF communication enhancement and degradation are possible. Offensive interference of this kind would likely be indistinguishable from naturally occurring space weather. This capability could also be employed to precisely locate the source of enemy electromagnetic transmissions.

VHF, UHF, and super-high frequency (SHF) satellite communications could be disrupted by creating artificial ionospheric scintillation. This phenomenon causes fluctuations in the phase and amplitude of radio waves over a very wide band (30 MHz to 30 GHz). HF modification produces electron density irregularities that cause scintillation over a wide-range of frequencies. The size of the irregularities determines which frequency band will be affected. Understanding how to control the spectrum of the artificial irregularities generated in the HF modification process should be a primary goal of research in this area. Additionally, it may be possible to suppress the growth of natural irregularities resulting in reduced levels of natural scintillation. Creating artificial scintillation would allow us to disrupt satellite transmissions over selected regions. Like the HF disruption described above, such actions would likely be indistinguishable from naturally occurring environmental events. Figure 4-4 shows how artificially ionized regions might be used to disrupt HF communications via attenuation, scatter, or absorption (fig. 4.4a) or degrade satellite communications via scintillation or energy loss (fig. 4-4b) (from Ref. 25).

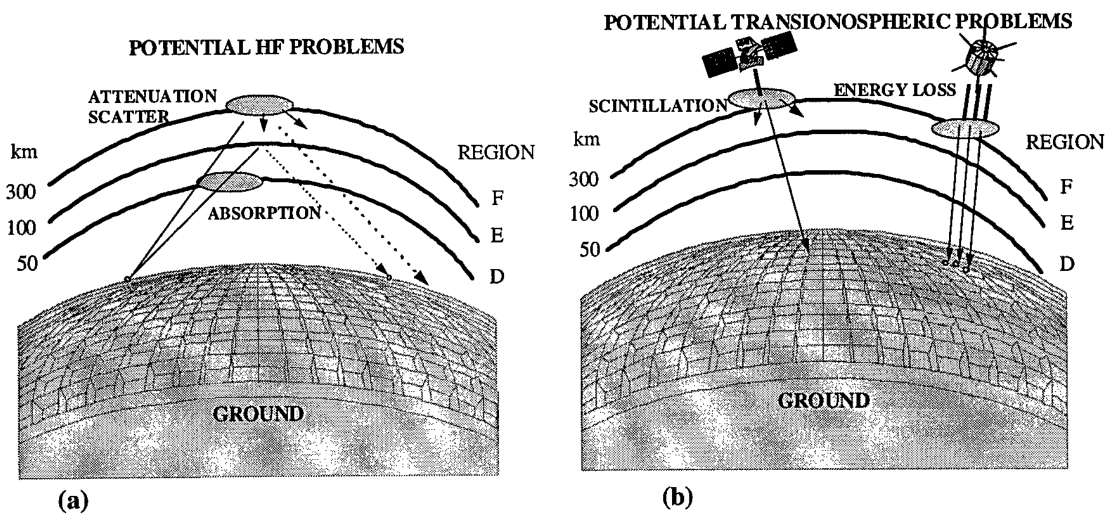

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Figure 4-4. Scenarios for Telecommunications Degradation

Exploding/disabling space assets traversing near-space. The ionosphere could potentially be artificially charged or injected with radiation at a certain point so that it becomes inhospitable to satellites or other space structures. The result could range from temporarily disabling the target to its complete destruction via an induced explosion. Of course, effectively employing such a capability depends on the ability to apply it selectively to chosen regions in space.

Charging space assets by near-space energy transfer. In contrast to the injurious capability described above, regions of the ionosphere could potentially be modified or used as-is to revitalize space assets, for instance by charging their power systems. The natural charge of the ionosphere may serve to provide most or all of the energy input to the satellite. There have been a number of papers in the last decade on electrical charging of space vehicles; however, according to one author, "in spite of the significant effort made in the field both theoretically and experimentally, the vehicle charging problem is far from being completely understood."[33] While the technical challenge is considerable, the potential to harness electrostatic energy to fuel the satellite's power cells would have a high payoff, enabling service life extension of space assets at a relatively low cost. Additionally, exploiting the capability of powerful HF radio waves to accelerate electrons to relatively high energies may also facilitate the degradation of enemy space assets through directed bombardment with the HF-induced electron beams. As with artificial HF communication disruptions and induced scintillation, the degradation of enemy spacecraft with such techniques would be effectively indistinguishable from natural environment effects. The investigation and optimization of HF acceleration mechanisms for both friendly and hostile purposes is an important area for future research efforts.

Artificial Weather

While most weather-modification efforts rely on the existence of certain preexisting conditions, it may be possible to produce some weather effects artificially, regardless of preexisting conditions. For instance, virtual weather could be created by influencing the weather information received by an end user. Their perception of parameter values or images from global or local meteorological information systems would differ from reality. This difference in perception would lead the end user to make degraded operational decisions.

Nanotechnology also offers possibilities for creating simulated weather. A cloud, or several clouds, of microscopic computer particles, all communicating with each other and with a larger control system could provide tremendous capability. Interconnected, atmospherically buoyant, and having navigation capability in three dimensions, such clouds could be designed to have a wide-range of properties. They might exclusively block optical sensors or could adjust to become impermeable to other surveillance methods. They could also provide an atmospheric electrical potential difference, which otherwise might not exist, to achieve precisely aimed and timed lightning strikes. Even if power levels achieved were insufficient to be an effective strike weapon, the potential for psychological operations in many situations could be fantastic.

One major advantage of using simulated weather to achieve a desired effect is that unlike other approaches, it makes what are otherwise the results of deliberate actions appear to be the consequences of natural weather phenomena. In addition, it is potentially relatively inexpensive to do. According to J. Storrs Hall, a scientist at Rutgers University conducting research on nanotechnology, production costs of these nanoparticles could be about the same price per pound as potatoes.[34] This of course discounts research and development costs, which will be primarily borne by the private sector and be considered a sunk cost by 2025 and probably earlier.

Concept of Operations Summary

Weather affects everything we do, and weather-modification can enhance our ability to dominate the aerospace environment. It gives the commander tools to shape the battlespace. It gives the logistician tools to optimize the process. It gives the warriors in the cockpit an operating environment literally crafted to their needs. Some of the potential capabilities a weather-modification system could provide to a war-fighting CINC are summarized in table 1, of the executive summary).

Notes

[1] A pilot program known as Project Popeye conducted in 1966 attempted to extend the monsoon season in order to increase the amount of mud on the Ho Chi Minh trail thereby reducing enemy movements. A silver iodide nuclei agent was dispersed from WC-130, F4 and A-1E aircraft into the clouds over portions of the trail winding from North Vietnam through Laos and Cambodia into South Vietnam. Positive results during this initial program led to continued operations from 1967 to 1972. While the effects of this program remain disputed, some scientists believe it resulted in a significant reduction in the enemy's ability to bring supplies into South Vietnam along the trail. E. M. Frisby, "Weather-modification in Southeast Asia, 1966–1972," *The Journal of Weather-modification* 14, no. 1 (April 1982): 1—3.

[2] William M. Gray et al., "Weather-modification by Carbon Dust Absorption of Solar Energy," *Journal of Applied Meteorology* 15 (April 1976): 355.

[3] Ibid.

[4] Ibid.

[5] Ibid., 367.

[6] AWS PLAN 813 Appendix I Annex Alfa (Scott AFB, Ill.: Air Weather Service/(MAC) 14 January 1972), 11. Hereafter cited as Annex Alfa.

[7] Capt Frank G. Coons, "Warm Fog Dispersal—A Different Story," *Aerospace Safety* 25, no. 10 (October 1969): 16.

[8] Annex Alfa, 14.

[9] Warren C. Kocmond, "Dissipation of Natural Fog in the Atmosphere," *Progress of NASA Research on Warm Fog Properties and Modification Concepts*, NASA SP-212 (Washington, D.C.: Scientific and Technical Information Division of the Office of Technology Utilization of the National Aeronautics and Space Administration, 1969), 74.

[10] James E. Jiusto, "Some Principles of Fog Modification with Hygrosopic Nuclei," *Progress of NASA Research on Warm Fog Properties and Modification Concepts*, NASA SP-212 (Washington, D.C.: Scientific and Technical Information Division of the Office of Technology Utilization of the National Aeronautics and Space Administration, 1969), 37.

[11] Maj Roy Dwyer, *Category III or Fog Dispersal*, M-U 35582-7 D993a c.1 (Maxwell AFB, Ala.: Air University Press, May 1972), 51.

[12] James McLare, *Pulp & Paper* 68, no. 8 (August 1994): 79.

[13] Milton M. Klein, *A Feasibility Study of the Use of Radiant Energy for Fog Dispersal*, Abstract (Hanscom AFB, Mass.: Air Force Material Command, October 1978).

[14] Edward M. Tomlinson, Kenneth C. Young, and Duane D. Smith, *Laser Technology Applications for Dissipation of Warm Fog at Airfields*, PL-TR-92-2087 (Hanscom AFB, Mass.: Air Force Material Command, 1992).

[15] J. Storrs Hall, "Overview of Nanotechnology," adapted from papers by Ralph C. Merkle and K. Eric Drexler, Internet address: http://nanotech.rutgers.edu/nanotech-/intro.html, Rutgers University, November 1995.

[16] Robert A. Sutherland, "Results of Man-Made Fog Experiment," *Proceedings of the 1991 Battlefield Atmospherics Conference* (Fort Bliss, Tex.: Hinman Hall, 3–6 December 1991).

[17] Christopher Centner et al., "Environmental Warfare: Implications for Policymakers and War Planners" (Maxwell AFB, Ala.: Air Command and Staff College, May 1995), 39.

[18] Louis J. Battan, *Harvesting the Clouds* (Garden City, N.Y.: Doubleday & Co., 1960), 120.

[19] Facts on File 55, no. 2866 (2 November 95).

[20] Gene S. Stuart, "Whirlwinds and Thunderbolts," *Nature on the Rampage* (Washington, D.C.: National Geographic Society, 1986), 130.

[21] Ibid., 140.

[22] Heinz W. Kasemir, "Lightning Suppression by Chaff Seeding and Triggered Lightning," in Wilmot N. Hess, ed., *Weather and Climate Modification* (New York: John Wiley & Sons, 1974), 623–628.

[23] SPACECAST 2020, *Space Weather Support for Communications*, white paper G, (Maxwell AFB, Ala.: Air War College/2020, 1994).

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[25] Lewis M. Duncan and Robert L. Showen, "Review of Soviet Ionospheric Modification Research," in *Ionospheric Modification and Its Potential to Enhance or Degrade the Performance of Military Systems*,(AGARD Conference Proceedings 485, October, 1990), 2-1.

[26] Ibid.

[27] Peter M. Banks, "Overview of Ionospheric Modification from Space Platforms," in *Ionospheric Modification and Its Potential to Enhance or Degrade the Performance of Military Systems* (AGARD Conference Proceedings 485, October 1990) 19-1.

[28] Capt Mike Johnson, *Upper Atmospheric Research and Modification—Former Soviet Union* (U), DST-18205-475-92 (Foreign Aerospace Science and Technology Center, AF Intelligence Command, 24 September 1992), 3. (Secret) Information extracted is unclassified.

[29] Capt Edward E. Hume, Jr., *Atmospheric and Space Environmental Research Programs in Brazil* (U) (Foreign Aerospace Science and Technology Center, AF Intelligence Command, March 1993), 12. (Secret) Information extracted is unclassified.

[30] Paul A. Kossey et al. "Artificial Ionospheric Mirrors (AIM)," in *Ionospheric Modification and Its Potential to Enhance or Degrade the Performance of Military Systems* (AGARD Conference Proceedings 485, October 1990), 17A-1.

[31] Ibid., 17A-7.

[32] Ibid., 17A-10.

[33] B. N. Maehlum and J. Troim, "Vehicle Charging in Low Density Plasmas," in *Ionospheric Modification and Its Potential to Enhance or Degrade the Performance of Military Systems* (AGARD Conference Proceedings 485, October 1990), 24-1.

[34] Hall.

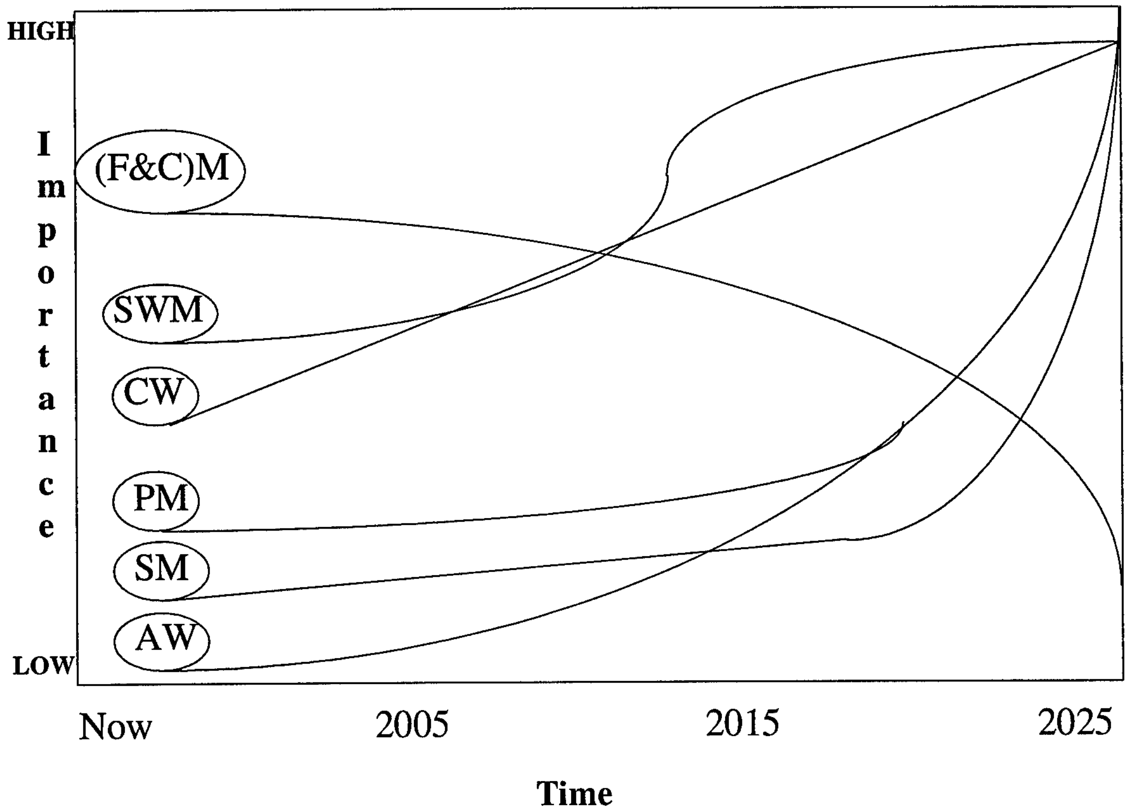
Chapter 5

Investigation Recommendations

How Do We Get There From Here?

To fully appreciate the development of the specific operational capabilities weather-modification could deliver to the war fighter, we must examine and understand their relationship to associated core competencies and the development of their requisite technologies. Figure 5-1 combines the specific operational capabilities of Table 1 into six core capabilities and depicts their relative importance over time. For example, fog and cloud modification are currently important and will remain so for some time to come to conceal our assets from surveillance or improve landing visibility at airfields. However, as surveillance assets become less optically dependent and aircraft achieve a truly global all-weather landing capability, fog and cloud modification applications become less important.

In contrast, artificial weather technologies do not currently exist. But as they are developed, the importance of their potential applications rises rapidly. For example, the anticipated proliferation of surveillance technologies in the future will make the ability to deny surveillance increasingly valuable. In such an environment, clouds made of smart particles such as described in chapter 4 could provide a premium capability.



Legend

PM	Precipitation Modification	**(F&C)M**	Fog and Cloud Modification
SM	Storm Modification	**CW**	Counter Weather
SWM	Space Weather-modification	**AW**	Artificial Weather

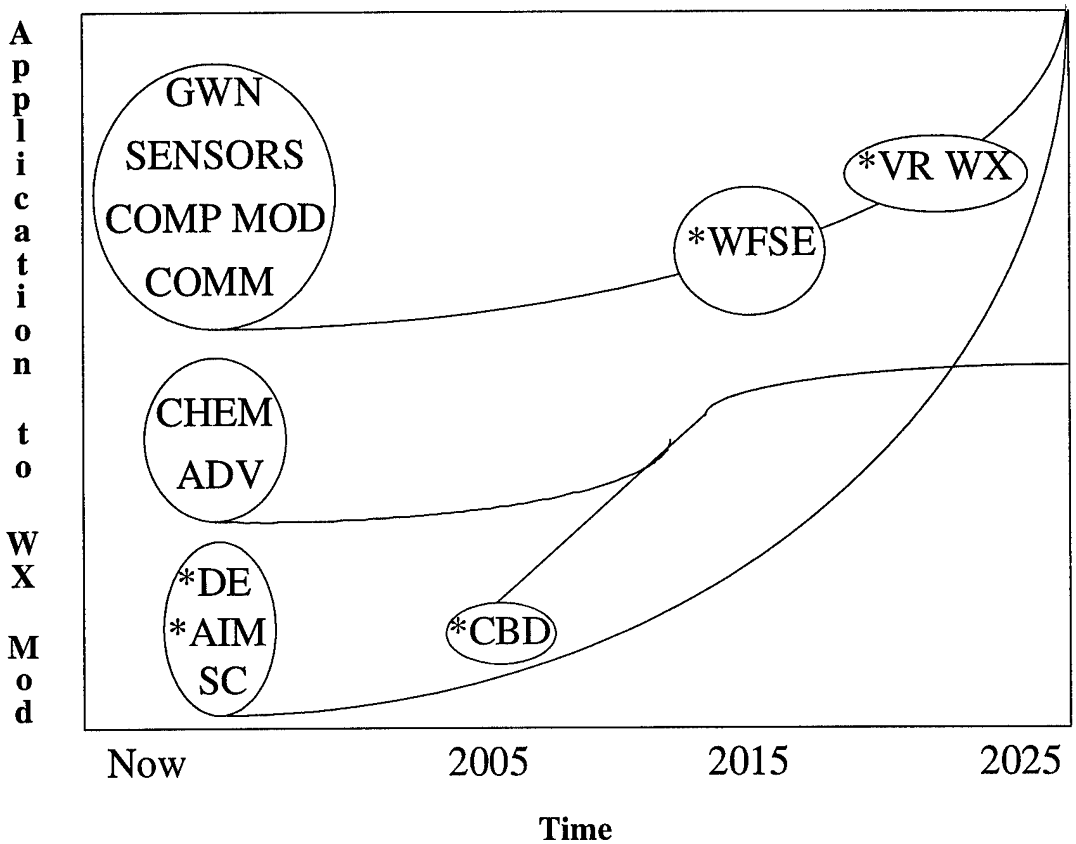
Figure 5-1. A Core Competency Road Map to Weather Modification in 2025.

Even today's most technologically advanced militaries would usually prefer to fight in clear weather and blue skies. But as war-fighting technologies proliferate, the side with the technological advantage will prefer to fight in weather that gives them an edge. The US Army has already alluded to this approach in their concept of "owning the weather."[1] Accordingly, storm modification will become more valuable over time. The importance of precipitation modification is also likely to increase as usable water sources become more scarce in volatile parts of the world.

As more countries pursue, develop, and exploit increasing types and degrees of weather-modification technologies, we must be able to detect their efforts and counter their activities when necessary. As depicted, the technologies and capabilities associated with such a counter weather role will become increasingly important.

The importance of space weather-modification will grow with time. Its rise will be more rapid at first as the technologies it can best support or negate proliferate at their fastest rates. Later, as those technologies mature or become obsolete, the importance of space weather-modification will continue to rise but not as rapidly.

To achieve the core capabilities depicted in figure 5-1, the necessary technologies and systems might be developed according to the process depicted in figure 5-2. This figure illustrates the systems development timing and sequence necessary to realize a weather-modification capability for the battlespace by 2025. The horizontal axis represents time. The vertical axis indicates the degree to which a given technology will be applied toward weather-modification. As the primary users, the military will be the main developer for the technologies designated with an asterisk. The civil sector will be the main source for the remaining technologies.



Legend

ADV	Aerospace Delivery Vehicles	**DE**	Directed Energy
AIM	Artificial Ionospheric Mirrors	**GWN**	Global Weather Network
CHEM	Chemicals	**SC**	Smart Clouds (nanotechnology)
CBD	Carbon Black Dust	**SENSORS**	Sensors
COMM	Communications	**VR WX**	Virtual Weather
COMP MOD	Computer Modeling	**WFSE**	Weather Force Support Element

* Technologies to be developed by DOD

Figure 5-2. A Systems Development Road Map to Weather Modification in 2025.

Conclusions

The world's finite resources and continued needs will drive the desire to protect people and property and more efficiently use our crop lands, forests, and range lands. The ability to modify the weather may be desirable both for economic and defense reasons. The global weather system has been described as a series of spheres or bubbles. Pushing down on one causes another to pop up.[2] We need to know when another power "pushes" on a sphere in their region, and how that will affect either our own territory or areas of economic and political interest to the US.

Efforts are already under way to create more comprehensive weather models primarily to improve forecasts, but researchers are also trying to influence the results of these models by adding small amounts of energy at just the right time and space. These programs are extremely limited at the moment and are not yet validated, but there is great potential to improve them in the next 30 years.[3]

The lessons of history indicate a real weather-modification capability will eventually exist despite the risk. The drive exists. People have always wanted to control the weather and their desire will compel them to collectively and continuously pursue their goal. The motivation exists. The potential benefits and power are extremely lucrative and alluring for those who have the resources to develop it. This combination of drive, motivation, and resources will eventually produce the technology. History also teaches that we cannot afford to be without a weather-modification capability once the technology is developed and used by others. Even if we have no intention of using it, others will. To call upon the atomic weapon analogy again, we need to be able to deter or counter their capability with our own. Therefore, the weather and intelligence communities must keep abreast of the actions of others.

As the preceding chapters have shown, weather-modification is a force multiplier with tremendous power that could be exploited across the full spectrum of war-fighting environments. From enhancing friendly operations or disrupting those of the enemy via small-scale tailoring of natural weather patterns to complete dominance of global communications and counter-space control, weather-modification offers the war fighter a wide-range of possible options to defeat or coerce an adversary. But, while offensive weather-modification efforts would certainly be undertaken by US forces with great caution and trepidation, it is clear that we cannot afford to allow an adversary to obtain an exclusive weather-modification capability.

Notes

[1] Mary Ann Seagraves and Richard Szymber, "Weather a Force Multiplier," *Military Review*, November/December 1995, 69.

[2] Daniel S. Halacy, *The Weather Changers* (New York: Harper & Row, 1968), 202.

[3] William Brown, "Mathematicians Learn How to Tame Chaos," *New Scientist*, 30 May 1992, 16.

Appendix A

Why Is the Ionosphere Important?

The ionosphere is the part of the earth's atmosphere beginning at an altitude of about 30 miles and extending outward 1,200 miles or more. This region consists of layers of free electrically charged particles that transmit, refract, and reflect radio waves, allowing those waves to be transmitted great distances around the earth. The interaction of the ionosphere on impinging electromagnetic radiation depends on the properties of the ionospheric layer, the geometry of transmission, and the frequency of the radiation. For any given signal path through the atmosphere, a range of workable frequency bands exists. This range, between the maximum usable frequency (MUF) and the lowest usable frequency (LUF), is where radio waves are reflected and refracted by the ionosphere much as a partial mirror may reflect or refract visible light.[1] The reflective and refractive properties of the ionosphere provide a means to transmit radio signals beyond direct "line-of-sight" transmission between a transmitter and receiver. Ionospheric reflection and refraction has therefore been used almost exclusively for long-range HF (from 3 to 30 MHz) communications. Radio waves with frequencies ranging from above 30 MHz to 300 GHz are usually used for communications requiring line-of-sight transmissions, such as satellite communications. At these higher frequencies, radio waves propagate through the ionosphere with only a small fraction of the wave scattering back in a pattern analogous to a sky wave. Communicators receive significant benefit from using these frequencies since they provide considerably greater bandwidths and thus have greater data-carrying capacity; they are also less prone to natural interference (noise).

Although the ionosphere acts as a natural "mirror" for HF radio waves, it is in a constant state of flux, and thus, its "mirror property" can be limited at times. Like terrestrial weather, ionospheric properties change from year to year, from day to day, and even from hour to hour. This ionospheric variability, called space weather, can cause unreliability in ground- and space-based communications that depend on ionospheric reflection or transmission. Space weather variability affects how the ionosphere attenuates, absorbs, reflects, refracts, and changes the propagation, phase, and amplitude characteristics of radio waves. These weather dependent changes may arise from certain space weather conditions such as: (1) variability of solar radiation entering the upper atmosphere; (2) the solar plasma entering the earth's magnetic field; (3) the gravitational atmospheric tides produced by the sun and moon; and (4) the vertical swelling of the atmosphere due to daytime heating of the sun.[2] Space weather is also significantly affected by solar flare activity, the tilt of the earth's geomagnetic field, and abrupt ionospheric changes resulting from events such as geomagnetic storms.

In summary, the ionosphere's inherent reflectivity is a natural gift that humans have used to create long-range communications connecting distant points on the globe. However, natural variability in the ionosphere reduces the reliability of our communication systems that depend on ionospheric reflection and refraction (primarily HF). For the most part, higher frequency communications such as UHF, SHF, and EHF bands are transmitted through the ionosphere without distortion. However, these bands are also subject to degradation caused by ionospheric scintillation, a phenomenon induced by abrupt variations in electron density along the signal path, resulting in signal fade caused by rapid signal path variations and defocusing of the signal's amplitude and/or phase.

Understanding and predicting ionospheric variability and its influence on the transmission and reflection of electromagnetic radiation has been a much studied field of scientific inquiry. Improving our ability to observe, model, and forecast space weather will substantially improve our communication systems, both ground and space-based. Considerable work is being conducted, both within the DOD and the commercial sector, on improving observation, modeling, and forecasting of space weather. While considerable technical challenges remain, we assume for the purposes of this study that dramatic improvements will occur in these areas over the next several decades.

[1] AU-18, *Space Handbook, An Analyst's Guide Vol. II.* (Maxwell AFB, Ala.: Air University Press, December 1993), 196.

[2] Thomas F. Tascione, *Introduction to the Space Environment* (Colorado Springs: USAF Academy Department of Physics, 1984), 175.

Appendix B

Research to Better Understand and Predict Ionospheric Effects

According to a SPACECAST 2020 study titled, "Space Weather Support for Communications," the major factors limiting our ability to observe and accurately forecast space weather are (1) current ionospheric sensing capability; (2) density and frequency of ionospheric observations; (3) sophistication and accuracy of ionospheric models; and (4) current scientific understanding of the physics of ionosphere-thermosphere-magnetosphere coupling mechanisms.[1] The report recommends that improvements be realized in our ability to measure the ionosphere vertically and spatially; to this end an architecture for ionospheric mapping was proposed. Such a system would consist of ionospheric sounders and other sensing devices installed on DoD and commercial satellite constellations (taking advantage in particular of the proposed IRIDIUM system and replenishment of the GPS) and an expanded ground-based network of ionospheric vertical sounders in the US and other nations. Understanding and predicting ionospheric scintillation would also require launching of an equatorial remote sensing satellite in addition to the currently planned or deployed DOD and commercial constellations.

The payoff of such a system is an improvement in ionospheric forecasting accuracy from the current range of 40-60 percent to an anticipated 80-100 percent accuracy. Daily worldwide ionospheric mapping would provide the data required to accurately forecast diurnal, worldwide terrestrial propagation characteristics of electromagnetic energy from 3-300 MHz. This improved forecasting would assist satellite operators and users, resulting in enhanced operational efficiency of space systems. It would also provide an order of magnitude improvement in locating the sources of tactical radio communications, allowing for location and tracking of enemy and friendly platforms.[2] Improved capability to forecast ionospheric scintillation would provide a means to improve communications reliability by the use of alternate ray paths or relay to undisturbed regions. It would also enable operational users to ascertain whether outages were due to naturally occurring ionospheric variability as opposed to enemy action or hardware problems.

These advances in ionospheric observation, modeling, and prediction would enhance the reliability and robustness of our military communications network. In addition to their significant benefits for our existing communications network, such advances are also requisite to further exploitation of the ionosphere via active modification.

Notes

[1] SPACECAST 2020, *Space Weather Support for Communications*, white paper G, (Maxwell AFB, Ala.: Air War College/2020, 1994).

[2] Referenced in ibid.

Appendix C

Acronyms and Definitions

AOC	air operations center
AOR	area of responsibility
ATO	air tasking order
EHF	extra high frequency
GWN	global weather network
HF	high frequency
IR	infared
LF	low frequency
LUF	lowest usable frequency
Mesoscale	less than 200 km^2
Microscale	immediate local area
MUF	maximum usable frequency
MW	microwave
OTH	over-the-horizon
PGM	precision-guided munitions
RF	radio frequency
SAR	synthetic aperture radar
SARSAT	search and rescue satellite-aided tracking
SHF	super high frequency
SPOT	satellite positioning and tracking
UAV	uninhabited aerospace vehicle
UV	ultraviolet
VHF	very high frequency
WFS	weather force specialist
WFSE	weather force support element
WX	weather

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