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.[19] 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.[20]

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."[21] 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.[22] 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.[23] 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 32oF. The best-known dissipation technique for cold fog is to seed it from the air with agents that promote the growth of ice crystals.[24]

Warm fog occurs at temperatures above 32^{o}F and accounts for 90 percent of the fog-related problems encountered by flight operations.[25] 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.[26] 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.[27] Optimal results require advance information on fog depth, liquid water content, and wind.[28]

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.[29] 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.[30]

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/m2 and would be very expensive.[31] 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.[32] 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.[33] 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.[34] 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.[35]

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,[36] 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.[37] 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.[38] 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.[39] 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.[40] 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.[41] 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."[42] 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.[43] 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.[44]

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).[45] 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.[46] 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."[47]

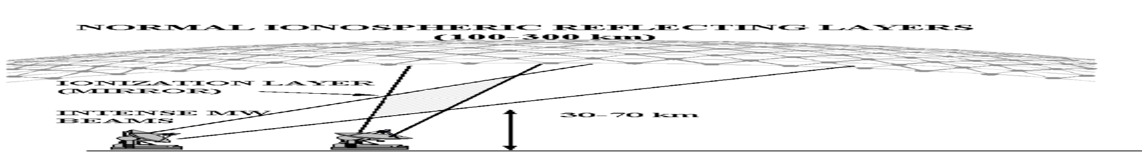
Several high-payoff capabilities that could result from the modification of the ionosphere or near space are described briefly below. It should be emphasized that this list is not comprehensive; modification of the ionosphere is an area rich with potential applications and there are also likely spin-off 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)."[48] 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.[49]

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.



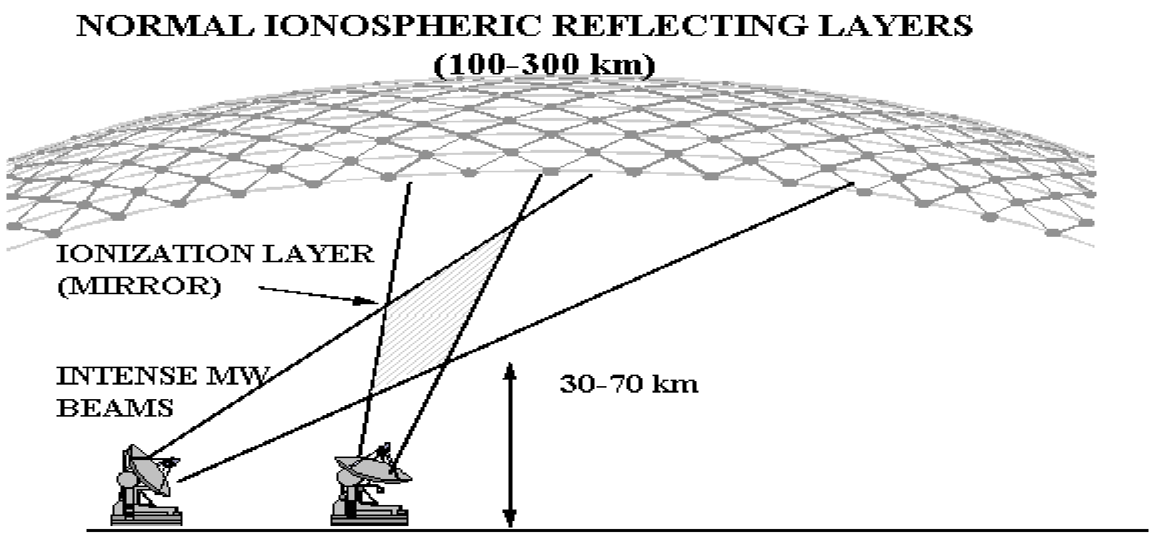


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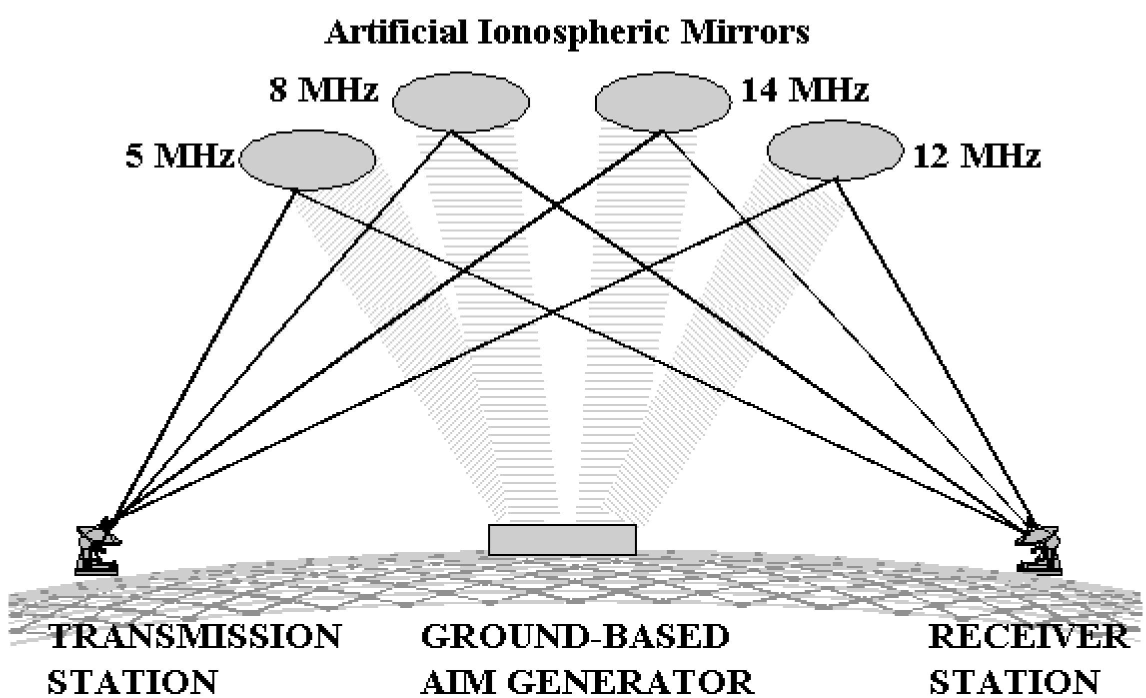
Figure 4-1. Crossed-Beam Approach for Generating an Artificial Ionospheric Mirror

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.[50]

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.

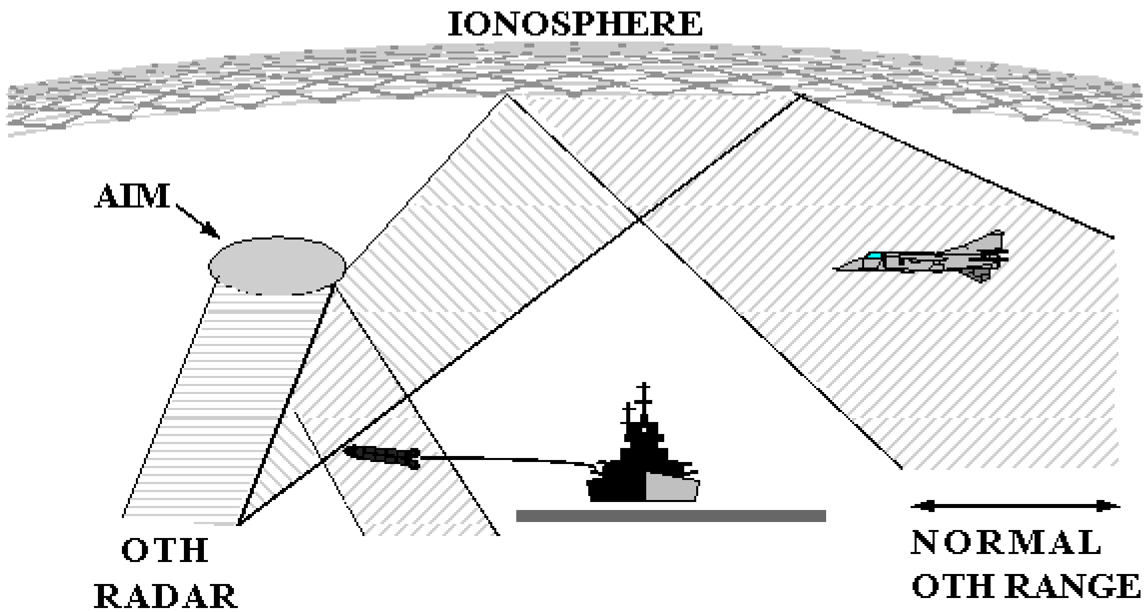


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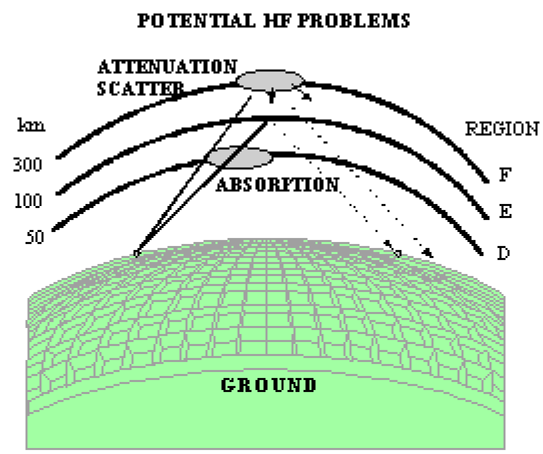
Figure 4-3. Artificial Ionospheric Mirror Over-the-Horizon Surveillance Concept.

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).



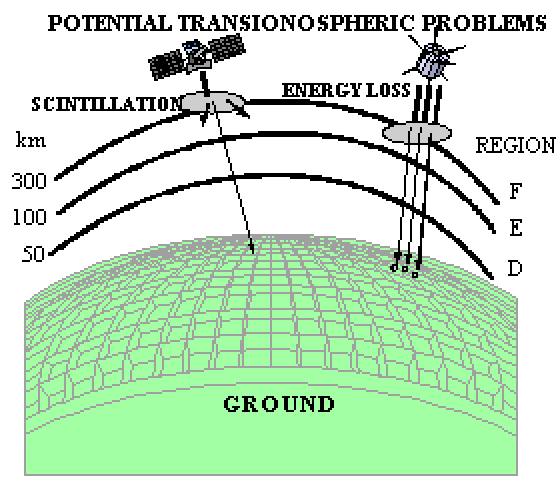


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Figure 4-4 (a) and (b). Scenarios for Telecommunications Degradation

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."[51] 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.[52] 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).

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