WMA Capabilities Statement on Weather Modification

Adopted April 2016

Capabilities Statement

Background

Under certain atmospheric conditions cloud microphysical and precipitation processes can be intentionally modified using existing cloud seeding methodologies to yield beneficial effects. Beneficial effects are those in which favorable benefit/cost ratios are realized without producing detrimental environmental impacts. The magnitudes and temporal/spatial scales of beneficial cloud seeding effects vary between project types and location. This statement covers the intentional application of cloud seeding technology and techniques (described below) covering areas from a few to several thousands of square kilometers for periods of hours to days. Larger-scale efforts to intentionally modify weather and climate regionally or globally using cloud-seeding or other technology and techniques, commonly referred to as geoengineering, are excluded from this discussion.

Increasing demands are being placed upon existing fresh water supplies throughout the world. These increasing demands lead to greater sensitivity to drought and to moderate precipitation shortfalls. Recent investigations have indicated that negative impacts of air pollution on precipitation downwind of some industrialized areas are probable. Concerns about water supplies are increasing interest in using cloud seeding techniques for precipitation augmentation. Hail damage to crops and property and fog-induced problems continue to produce interest in their mitigation. These factors, combined with the typically attractive benefit/cost ratios associated with operational cloud seeding projects, have fostered ongoing and growing interest in intentional weather modification.

Brief capability statements regarding intentional weather modification by cloud seeding follow, summarizing the current state of the technology within the primary application categories. The summaries are limited to conventional cloud seeding methods that are based on accepted physical principles. Regional differences in cloud microphysics, atmospheric temperature, frequency of seedable cloud system occurrence, orographic influences, seeding agent selection, delivery and dosage rates, and quality and completeness of operational execution, can alter these expectations. A more detailed treatment of weather modification capabilities, position statements, and the status of the discipline can be found in Guidelines for Cloud Seeding to Augment Precipitation, 3rd Edition, ASCE Manuals and Reports on Engineering Practice No. 81, American Society of Civil Engineers, Reston, VA, 2016.

The potential environmental impacts of cloud seeding have been addressed in many studies. No significant adverse environmental impacts have been found due to use of silver iodide, the most commonly used seeding material, even in project areas where seeding has been conducted for fifty years or more. A more comprehensive discussion on environmental implications of using silver iodide in cloud seeding along with references can be found in a published WMA policy statement, The Environmental Impact of Using Silver Iodide as a Cloud Seeding Agent, July 2009, (WMA website, http://weathermod.org/aboutus/).

Claims regarding other methods of intentional weather modification involving hail cannons and ionization generators have not been scientifically substantiated to date. The Weather Modification Association does not currently endorse those methods.

Fog and Stratus Dispersal

The dispersal of shallow, supercooled (colder than 0°C) fog or stratus cloud decks is an established operational technology. The effects from dispersing supercooled fog and stratus are easily measured and the results highly predictable. Hence, randomized statistical verification has generally been considered unnecessary.

Dispensing ice phase seeding agents, such as dry ice, liquid nitrogen, liquid propane, or silver iodide into supercooled fog and stratus is effective in improving visibility. Clearings established in cloud decks embedded in strong wind fields fill in quickly, unless seeding is done nearly continuously. Selection of a suitable technique is dependent upon wind, temperature, and other factors. Dry ice has commonly been used in airborne delivery systems. Liquid carbon dioxide, liquid nitrogen, and liquid propane have been used in ground-based delivery systems at some airports.

The dispersal of warm (warmer than 0°C) fog or stratus decks over areas as large as airport runways has been operationally applied via introduction of a significant heat source. The mixing of drier air into shallow fog by helicopter downwash can create localized clearings. Various hygroscopic (water attracting) substances have also been used to improve visibility in these situations, but with less satisfactory results than in supercooled fog.

Winter Precipitation Augmentation

The capability to increase precipitation from wintertime orographic cloud systems has been demonstrated in a number of research experiments. The evolution, growth, and fallout of seeding-induced (and enhanced) ice particles have been documented in several mountainous regions of the western United States. Enhanced precipitation rates up to about 1 mm per hour have been measured in seeded cloud regions. Although conducted over smaller temporal and spatial scales, research results tend to be consistent with evaluations of randomized experiments in larger project areas as well as a substantial and growing number of operational projects. Increases of 5% - 15% in winter season precipitation have been consistently reported in target areas that are effectively treated by cloud seeding projects, and generally accepted by the scientific community. Similar results have been found in both continental and coastal mountain regions. The consistent range of indicated effects in many regions suggests widespread transferability of the estimated results for supercooled orographic clouds.

Wintertime snowfall augmentation projects can use a combination of aircraft and ground-based dispersing systems. Although silver iodide compounds are still the most commonly used glaciogenic (ice forming) seeding agents, dry ice is used in some warmer (but still supercooled) cloud situations. Liquid propane also shows some promise as a seeding agent when dispensers can be positioned above the freezing level on the upwind slopes of mountains at locations sufficiently far upwind to allow growth and fallout of precipitation within the intended target areas. Dry ice and liquid propane expand the window of opportunity for seeding over that of silver iodide, since they can produce ice particles at temperatures as warm as -0.5^{o}C. For effective precipitation augmentation, cloud seeding methods and guidelines need to be adapted to regional meteorological and topographical characteristics.

Technological advances have aided winter precipitation augmentation projects. Fast-acting silver iodide ice nuclei, with higher activity at warmer temperatures, have increased the capability to augment precipitation in shallow orographic cloud systems. Computer models have been developed to simulate atmospheric transport, as well as meteorological and microphysical processes involved in cloud seeding; and these models are coming into use in operations. Finer scale atmospheric computer models are currently showing skill in predicting the amount of natural precipitation down to short time intervals such as individual storm periods. High resolution airborne radar and lidar systems are being used to study the fine scale structure of air motion and cloud and precipitation particle evolution in the boundary layer over mountainous terrain. These airborne remote sensing instruments are capable of documenting changes in cloud structure that may be occurring due to cloud seeding processes, and in the cloud regions that are the most difficult to observe by in situ aircraft probes or ground-based radar. Improvements in computer and communications systems have resulted in a steady improvement in remotely controlled ground-based silver iodide generators, permitting improved positioning and reliable operation in remote mountainous locations. Equipment improvements include solution flow control and atomization technology. There have been improvements in silver iodide flare rack designs and flare sizes. Also, improvements in weather prediction and remote meteorological measurement telemetry are advancing capabilities in weather modification technology.

Traditional statistical methods continue to be used to evaluate both randomized and non-randomized wintertime precipitation augmentation projects. Highly accurate quantitative precipitation prediction, especially for orographic situations, is providing a promising option for evaluation of cloud seeding experiments. Results from similar seeding projects are also being pooled objectively to obtain more robust estimates of cloud seeding efficacy. Objective evaluations of non-randomized operational projects continue to be a difficult challenge. Some new methods of evaluation using the trace chemical and physical properties of segmented snow profiles have been used to establish targeting effectiveness and estimate precipitation augmentation over basin-sized target areas.

Summer Precipitation Augmentation

The capability to augment summer precipitation from convective clouds has been demonstrated in some project areas, and the scientific community places a lower degree of confidence in the indicated effects of these efforts compared to that for winter precipitation augmentation, for a number of reasons, especially their cloud dynamical differences. Augmentation of summer precipitation normally involves delivery of either hygroscopic (water-attracting) or glaciogenic (ice-forming) aerosols into the updraft regions at the bases or above the freezing level of the subject clouds with the intention of modifying the clouds' internal microphysical structure to enhance the growth of precipitation particles. The modification of cloud microphysics and precipitation inevitably feeds back to cloud dynamics such that the two processes combined alter the precipitation further. The outcomes of the seeding depend strongly on the initial conditions.

Results from research projects conducted on summertime cumulus clouds are encouraging but somewhat variable. Part of the resulting uncertainty is due to the variety of climatological and microphysical settings in which experimentation has been conducted. Other important factors include the spatial scale at which the investigations are conducted and the seeding mode. A research project that combines the statistical results with microphysical documentation of the way in which rain enhancement is achieved is still lacking.

Assessments of some operational and research projects that have seeded selected individual clouds or clusters of clouds with either glaciogenic or hygroscopic nuclei have found that seeded clouds tend to last longer, expand or travel farther to cover larger areas, and are more likely to merge with nearby clouds and produce more precipitation. Both dynamic and microphysical changes appear to be involved.

Most summertime seeding projects have been evaluated using radar data, making it possible that some of the seeding results have been confounded by seeding-induced changes in the drop sizes that will in turn affect the radar reflectivities and the inferred rainfall rate. This would tend to exaggerate the seeding effect. This uncertainty applies especially to hygroscopic cloud seeding efforts in which the goal is to increase the droplet sizes.

Evaluations of operational summer precipitation augmentation projects present a difficult problem due to their non-randomized nature and the normally large temporal and spatial variability present in summertime rainfall. Recognizing these evaluation limitations, various methods for the evaluation of such projects have been developed and used, ranging in scale from individual clouds to floating targets of varying sizes to area-wide analyses. The results of many of these evaluations, at the single cloud scale through floating target areas up to 2,000 km2, have indicated a positive seeding effect in precipitation. Area-wide effects can be more difficult to discern due to the large temporal and spatial variability in summertime rainfall noted earlier. In some instances, apparent positive effects of seeding have also been noted outside the specific targets. Thus, the apparent effect of seeding is not necessarily confined to the directly-treated clouds. The physical mechanisms leading to those effects outside the directly-treated clouds are not yet fully understood.

Technological advances have aided summer precipitation augmentation projects. These include fast-acting silver iodide ice nuclei, new hygroscopic seeding formulations, polarimetric radars, satellite-based microphysical observations of the clouds, sophisticated radar and satellite data processing and analysis capabilities, advancements in airborne cloud physics instrumentation, and full bin microphysics numerical modeling.

Hail Suppression

The capability to suppress damaging hail continues to improve. Attracted by potentially large benefit/cost ratios, many countries are conducting projects where hailstorms are seeded to reduce the damage caused by hail. While there are a number of conceptual models regarding the formation and mitigation of hail, the most common treatment method for hail suppression involves the addition of high concentrations of ice nuclei (usually silver iodide smoke particles) into the new growth regions of storms from aircraft or ground-based sources to manipulate the hail embryo formation process and thus limit the growth of hailstones.

Evaluations of carefully conducted hail suppression research and operational projects have shown statistically significant reduction in damage caused by hail to agricultural crops and property. Studies of long-standing hail suppression operations in a number of locations around the world indicate a range of effects from 25% to 75% reduction in damage. Advances in radar data processing and evaluation techniques are helping to provide additional insights into the effects of cloud seeding. Microphysical measurements from single-cloud studies and radar analyses are also providing encouraging evidence consistent with the conceptual models of hail suppression. These technological advances and research efforts continue to develop improved understanding of hail growth and hail suppression.

The Weather Modification Association does not endorse the use of hail cannons. To date there is a lack of what the WMA considers to be any scientific evidence that hail cannons produce an effect on a thunderstorm's ability to produce hailstones, including the reduction of damaging hail from those storms. Furthermore, there is no scientifically based expectation that this method will work.

Status of the Discipline

The fundamental principles and primary cloud treatment strategies involved in weather modification are reasonably well understood and a substantial body of evidence regarding the effectiveness of cloud seeding exists. Attainment of desirable weather modification effects depends upon several factors, including the weather regimes of a specific area and their meteorological characteristics, the design of a project to achieve a specified goal, and effective targeting of the seeding agents into the right clouds in space and time.

The "level of evidence" issue regarding weather modification effectiveness remains a topic of some debate in the scientific community. An increasing number of cloud seeding practitioners, scientists, sponsors, and investigators accept the growing body of primarily statistical results along with some objective physical evidence in support of cloud seeding for beneficial effects. Also there are scientists who are not convinced by the current level of evidence, especially regarding precipitation enhancement efficacy, and who recommend further research to demonstrate replication of results. Furthermore, the physical impacts of seeding using hygroscopic nuclei on precipitation efficiency are less certain than those involving ice nuclei type seeding. The ranges of effects discussed in this WMA Statement on Weather Modification Capabilities take into account: a) the statistically significant results of some carefully controlled-randomized experiments, b) the physical evidence obtained through laboratory and atmospheric experimentation and observation, c) the ability to replicate the results with cloud simulations, and d) the results of less robust statistical evaluations of large numbers of non-randomized cloud seeding projects over decades. It remains to those considering application of cloud seeding technologies to determine what level of evidence is appropriate for their decision-making.

Persisting challenges in weather modification include determining and defining the conditions under which predictable and consistent effects may be achieved, and establishing and executing the most effective cloud treatment strategies. It also appears that, in some situations, the effects of air pollution, desert dust, and sea salt aerosols on precipitation can confound estimation of the effectiveness of cloud seeding, such that these effects should be considered in the design, execution, and evaluation of cloud seeding projects. It is also important to continue the development and application of methods for estimating the effectiveness of weather modification projects, especially operations conducted without randomization. Continued applied research into weather modification issues is encouraged.

Incremental advances in the science and technology of weather modification will lead to improvements in cloud seeding opportunity recognition, treatment strategies, and methods for evaluating cloud seeding effectiveness. Such advances will lead toward eventual optimization and broader acceptance of cloud seeding applications and, thus, fuller realization of the potential of this technology. In recognition of this the WMA encourages continued objective investigation of these processes using new instrument and modeling tools as these become available.