Weather Modification Assoc

Promoting research, development and underst
of weather modification for beneficial use

WMA Capabilities Statement on Weather Modification

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Background

It has been established that certain aspects of the weather, specifically cloud microphysical and precipitation processes, can be intentionally modified under various circumstances. Beneficial effects, those in which favorable benefit/cost ratios are realized without producing any detrimental environmental impacts, can be achieved within each of the major categories of cloud modification using existing treatment (cloud seeding) methodologies. The magnitudes and temporal/spatial scales of seeding effects vary between and within those major categories. It has also been established that unintentional anthropogenic effects (those caused by human activity) on weather do occur, and are commonly referred to as inadvertent weather modification. These inadvertent effects can be manifested by modifications to air quality, temperatures, and precipitation patterns and intensities. The precipitation effects can be positive or negative.

Increasing demands are being placed upon existing fresh water supplies throughout the world. These increasing demands lead to greater sensitivity to drought and to even moderate precipitation shortfalls. Recent investigations indicate negative impacts of air pollution on precipitation downwind of some industrialized areas and areas that practice open burning of vegetation. Concerns about water supplies are producing increasing interest in the application of cloud seeding 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 seeding programs, 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 its primary application categories. The summaries are limited to conventional seeding methods that are based on accepted physical principles. A more detailed treatment of weather modification capabilities and the status of the discipline can be found in Volume 36 (2004) of the WMA Journal in a review panel report: The Weather Modification Association Response to the National Research Council's Report Titled "Critical Issues in Weather Modification Research." A word of caution is necessary concerning these generalized capability statements, specifically regarding the transferability of results. Regional differences in cloud microphysics, atmospheric temperature structure, 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.

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.

Fog and Stratus Dispersal

The dispersal of shallow, supercooled (colder than 0o 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 0o 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, primarily in military applications.

Winter Precipitation Augmentation

The capability to increase precipitation from wintertime orographic cloud systems has now been demonstrated successfully in numerous "links in the chain" research experiments. The evolution, growth and fallout of seeding-induced (and enhanced) ice particles have been documented in several mountainous regions of the western U. S. Enhanced precipitation rates in seeded cloud regions have been measured in the range of hundredths to >1 mm per hour. Although conducted over smaller temporal and spatial scales, research results tend to be consistent with evaluations of randomized experiments and a substantial and growing number of operational programs where 5% - 15% increases in seasonal precipitation have been consistently reported. Similar results have been found in both continental and coastal regions, with the potential for enhanced precipitation in coastal regions appearing to be greater in convective cloud regimes. The consistent range of indicated effects in many regions suggests fairly widespread transferability of the estimated results.

Technological advances have aided winter precipitation augmentation programs. Fast-acting silver iodide ice nuclei, with higher activity at warmer temperatures, have increased the capability to augment precipitation in shallow orographic cloud systems. Numerical modeling has improved the understanding of atmospheric transport processes and allowed simulation of the meteorological and microphysical processes involved in cloud seeding. Improvements in computer and communications systems have resulted in a steady improvement in remotely controlled cloud (ice) nuclei generators (CNG's), which permit improved placement of CNG's in remote mountainous locations.

Wintertime snowfall augmentation programs can use a combination of aircraft and ground-based dispersing systems. Although silver iodide compounds are still the most commonly used glaciogenic (causing the formation of ice) 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 adequately 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 -0.5o C... For effective precipitation augmentation, seeding methods and guidelines need to be adapted to regional meteorological and topographical situations.

Although traditional statistical methods continue to be used to evaluate both randomized and non-randomized wintertime precipitation augmentation programs, the results of similar programs are also being pooled objectively in order to obtain more robust estimates of seeding efficacy. Objective evaluations of non-randomized operational programs continue to be a difficult challenge. Some new methods of evaluation using the trace chemical and physical properties of segmented snow profiles show considerable promise as possible means of quantifying precipitation augmentation over basin-sized target areas.

Summer Precipitation Augmentation

The capability to augment summer precipitation from convective clouds has been reasonably well demonstrated. Assessments of some operational and research programs 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.

Results from research programs 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. Projects which relied upon introduction of glaciogenic seeding material targeted for specific clouds or portions of clouds that met certain criteria (based essentially upon the stage of development of the clouds) have generally indicated positive seeding effects, ranging between 50% and 100% for individual clouds and on the order of 50% for clusters of convective clouds.

Evaluations of operationally conducted summer precipitation augmentation programs 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 programs 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 1,700 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 programs. These include fast-acting silver iodide ice nuclei, new hygroscopic seeding formulations, sophisticated radar and satellite data processing and analysis capabilities, airborne cloud physics instrumentation and continued improvements in numerical modeling.

Hail Suppression

The capability to suppress damaging hail continues to improve. Attracted by potentially large benefit-to-cost ratios, many countries are conducting programs where hailstorms are seeded to reduce the damage caused by hail. While there are a number of concepts 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 operations have demonstrated a 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 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.

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 program to achieve a specified goal, and the execution of the program.

The "level of evidence" issue regarding weather modification effectiveness remains a topic of some debate. An increasing number of cloud seeding practitioners, sponsors and investigators accept the growing body of primarily statistically expressed, but also objective physical evidence in support of cloud seeding for beneficial effects. The ranges of effects shown in this Capability Statement 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 and c) 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, air pollution effects on precipitation can confound estimation of the effectiveness of cloud seeding, such that the potential for pollution effects should be considered in the design, execution and evaluation of cloud seeding programs. It is also important to continue the development and application of methods for estimating the effectiveness of weather modification projects, especially operational projects 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.

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